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CONVENTIONAL MACHINING OF ESR 4340 STEEL.(U)

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MANUFACTURING METHODS AND TECHNOLOGY (MANTECH) PROGRAM

CONVENTIONAL MACHINING OF ESR 4340 STEEL

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July 1980

FINAL REPORT

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This program involved the study of conventional machining of heat treated ESR 4340 steel (Rc 54-57). Initial effort involved a survey of available data regarding the machining of high strength steels with hardnesses of Rc 50 and above. A machining program was conducted, determining optimum tools and conditions for turning, drilling, face milling, end milling, and grinding operations. Effects of various parameters including cutting speeds, feeds,

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depths of cut, and cutting fluids on tool life was determined. All the operations were found to be extremely difficult and application of conventional procedures is not feasible. Tool lives remained short despite reductions in speeds and feeds. Conventional grinding methods induced detrimental residual tensile stresses along the surface, resulting in cracking, lapping, and untempered martensitic structures. Low stress grinding techniques were found to be applicable to this material when proper dressing procedures and reduced rates were used.

SUMMARY

Hughes Helicopters (HH) under Army Contract DAAG 46-78-C-0046 has completed a study of the conventional machining of ESR 4340 steel. The objective of this program was to optimize procedures and develop an efficient machining specification. Metcut Research Associates, a leader in the research and development of metal removal technology, was the subcontractor.

The program conducted between September 1978 through March 1980 was sponsored by U. S. Army Aviation Reserach and Development Command (AVRADCOM), St. Louis, Missouri and monitored by U. S. Army Materials and Mechanics Research Center (AMMRC) Watertown, Massachusetts, under the direction of Mr. Arthur Ayvazian. The machining tests were conducted at Metcut under the direction of Mr. J. Kohls and Mr. J. Christopher. The project was coordinated by the HH project engineer, Mr. K. Niji, with the assistance of Mr. J. Leach of the Manufacturing Department.

ESR 4340 steel is presently being used for various critical parts on the YAH-64 for its high ballistic tolerance characteristics. Its advantageous qualities of high hardness and toughness creates great difficulties in machining. Because of its relatively new usage, there is no manufacturing source of information which presents an efficient machining method for this material. This program was designed to resolve that problem.

This program was initially conceived as an 18-month two-phase program. Phase I began with an initial survey of available data regarding the machining of ESR 4340 steel. A machining test program was then developed and conducted, studying the effects of various parameters in turning, drilling, milling, and grinding. Optimum tools and conditions were obtained for these operations. All of the operations were found to be extremely difficult and application of conventional procedures is not feasible. Tool lives remained short despite reductions in speeds and feeds. Conventional grinding methods induced detrimental residual tensile stresses along the surface, resulting in cracking, lapping, and untempered martensitic structures. Low stress grinding techniques, emphasizing wheel dressing procedures and reduced speeds and downfeeds, proved to be applicable to this material. In view of most of the machining results, Phase II involving the application of Phase I findings to the fabrication of YAH-64 components was cancelled. Studies involving alternative methods are now being considered.

CONTENTS

INTRODUCTION

Hughes Helicopters (HH), with the assistance of Metcut Research Associates as a major subcontractor, has completed a program studying conventional machining methods for ESR 4340 steel in an attempt to develop an efficient machining procedure. Hughes Helicopters is interested in the development of such a procedure for ESR 4340 steel since many of the components in the drive system, flight control system and hydraulic subsystem of the YAH-64 are made from this material. Figure 1 and Table I illustrate the areas where these parts are located. This material is being used to make these various parts specifically because of its high ballistic tolerance characteristics. Parts made of ESR 4340 steel tend to withstand the impact of a 12.7 mm armor piercing round or the explosive energy of a 23 mm HEI (high explosive incendiary) round that might completely fragment parts made of normal 4340 steel.

The low non-metallic inclusion content, the high density of the material, and the uniformity of structure provides ESR steel with its toughness quality, while still maintaining its high hardness (Rc 54-57 in the heat treated condition). Defects such as central porosity and line inclusion accumulations in rolled and forged plates are virtually eliminated. The uniform structure obtained from the electroslag remelt process produces a material whose yield strength and fracture toughness are similar in both transverse and longitudinal directions. These high properties in the short transverse direction permits reductions in plate thickness, subsequently reducing weight and material costs.

The qualities that make application of ESR steel so advantageous also create difficulties in machining the material. The desulfurization and oxide inclusion removal, which results in the clean steel, removes elements which enhance machinability. Because of its relatively new usage, there is no manufacturing specification which deals with the efficient machining of ESR 4340 steel.

After an initial survey of available information regarding the machining of ESR 4340 steel and other high hardness materials, tests were conducted to ascertain the effects of various parameters such as cutting speeds, feeds and fluids. An assortment of carbide tools, along with various ceramics for turning, and high speed steels for drilling, were obtained and studied during the course of the machining tests. A determination of optimum tools and conditions were made for turning, drilling, face milling, end milling, and grinding operations. The optimum tools and conditions are presented and discussed in this report.

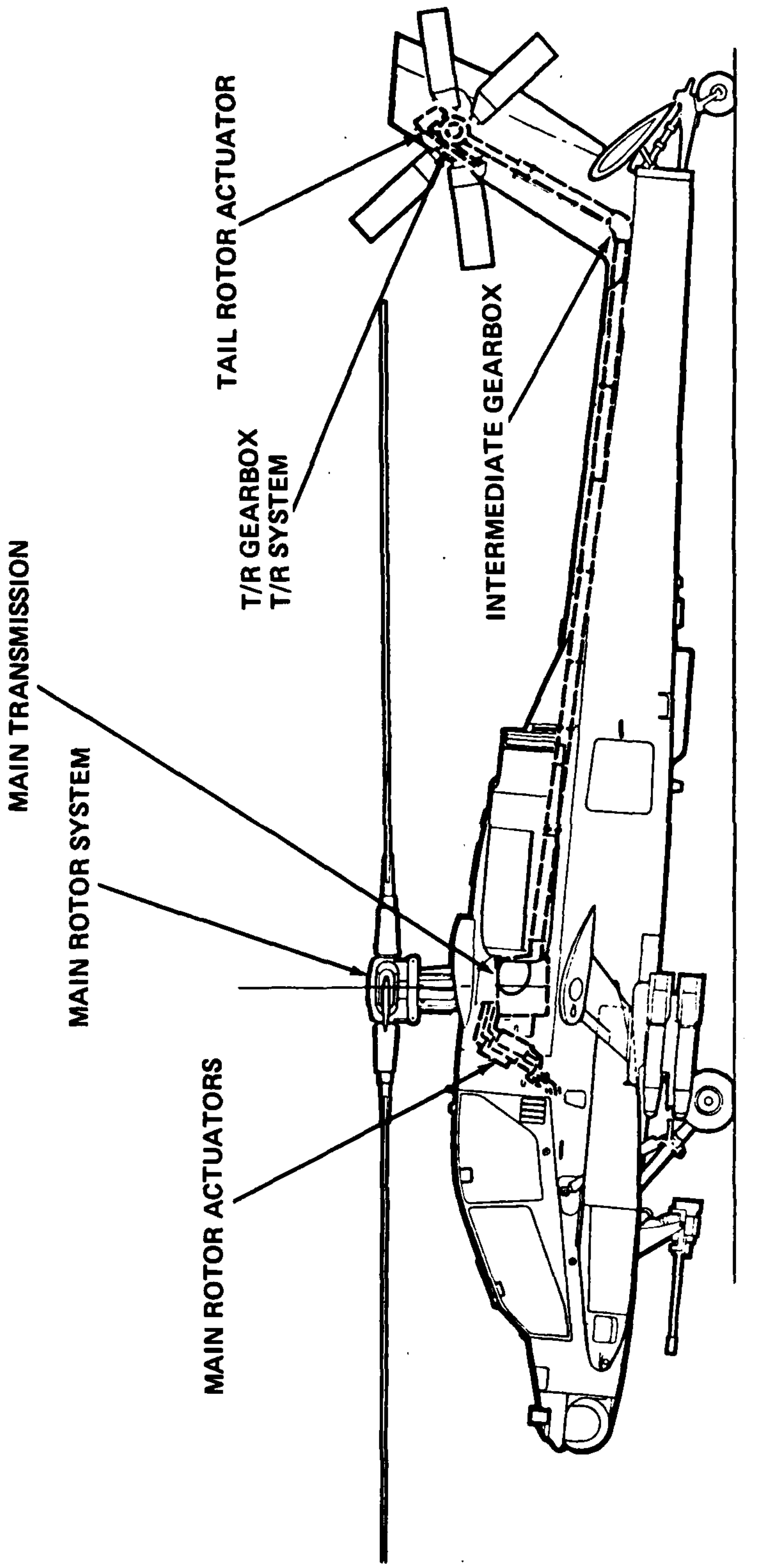


Figure 1. Critical Areas Where ESR 4340 Steel is Used on the YAH-64

TABLE I. ESR STEEL YAH-64 HELICOPTER COMPONENT PARTS

Name	Part Number	No. of Pieces	Finished Weight (lb)
DRIVE			
Main Transmission			
Intermediate Gear Bearing Retainer	7-113100122	1	2.3
T/R Helical Pinion Retainer	7-113100125	1	0.9
Rotor Brake Adapter	7-113100131	2	2.4
Input Pinion Bearing Adapter	7-113100132	2	2.4
Intermediate Gear Roller Bearing Liner	7-113100143	1	3.0
Input Bevel Gear Bearing Liner	7-113100144	2	5.8
Input Bevel Gear Bearing Sleeve	7-113100145	2	6.2
T/R Helical Gear Sleeve	7-113100146	1	0.5
Gen. Roller Bearing Sleeve	7-113100148	2	0.2
Gen. Ball Bearing Sleeve	7-113100149	2	0.5
Rotor Brake Roller Bearing Sleeve	7-113100150	2	1.0
Input Pinion Thrust Bearing Sleeve	7-113100154	2	6.8
Input Pinion Roller Bearing Sleeve	7-113100155	2	1.0
Hydraulic Pump Gear Bearing Sleeve	7-113100156	8	1.3
Intermediate Gearbox			
Roller Bearing Output Sleeve	7-113300143	1	0.4
Duplex Ball Bearing Sleeve	7-113300144	2	4.2
Roller Bearing Input Sleeve	7-113300147	1	0.4
Tail Rotor Gearbox			
Input Gear Sleeve	7-113400143	1	2.6
Input Gear Roller Bearing Sleeve	7-113400144	1	0.6
Output Gear Roller Bearing Sleeve	7-113400145	1	1.3
Output Gear Sleeve	7-113400146	1	2.5

TABLE I. ESR STEEL YAH-64 HELICOPTER COMPONENT PARTS (CONT)

Name	Part Number	No. of Pieces	Finished Weight (lb)
FLIGHT CONTROL AND ROTOR GROUP			
Main Rotor			
Rotating SP Bearing Retainer	7-211511204	1	7.0
Adj Pitch Link Barrels	7-211511136	4	5.1
Pitch Link Rod Ends	7-211511137	4	8.4
Tail Rotor			
Rotating Swashplate	7-211527003	1	7.8
Swashplate Bearing Retainer	7-211527016	1	3.3
HYDRAULIC SUBSYSTEM			
Main Rotor Actuators			
Longitudinal		1	49.1
Lateral		1	38.6
Collective		1	44.4
Tail Rotor Actuator		1	32.6
SHIPSET TOTAL	26	53	242.6

DISCUSSION

This effort was originally planned as a two phase program. The first phase would primarily involve testing by Metcut to determine best conditions for achieving high machining efficiency. The second phase would apply this information to the fabrication of small YAH-64 components.

The first task in Phase I involved a survey by Hughes Helicopters and Metcut reviewing current manufacturing procedures being followed regarding ESR 4340. Little or no attempt was being made to finish machine parts by any of the vendors or subcontractors. Major Hughes Helicopters subcontractors working on the AAH program using ESR 4340 steel, included Aircraft Gear (T/R gearbox components), Bendix (drive train components) Bertea (hydraulic actuators), and Litton (main transmission components). The procedure most commonly followed, primarily involved rough machining in the annealed state, then slow grinding of 0.050 - 0.070 inches of material to finished dimensions after heat treatment. Most of the data gathered was obtained through a literature survey conducted at Metcut's Machinability Data Center. Data regarding the machining of high hardness metals ($50R_C$ and above) have been compiled in a form similar to the data sheets in the Machining Data Handbook and are presented as Appendix A. Data for turning (carbide and ceramic), drilling, face milling, end milling, tapping, and grinding have been gathered and grouped by operation and hardness ranges. The information was to be used to find a starting point for tools and parameter values for our efforts in machining ESR 4340 steel.

The initial step in the program was to fabricate test specimens. The ESR process involves remelting a consumable electrode at atmospheric pressure in a superheated molten slag bath which protect the molten metal from atmospheric contamination. Electricity is passed through the slag, generating enough heat to melt the end of the electrode which is immersed in the slag. The ESR ingot grows through progressive solidification of the molten metal in a water cooled mold. The solidification characteristics are greatly influenced by the size, shape and temperature of the molten metal pool. After the ingots are solidified, they are forged to various standard rounds and round corner squares. HMS 6-1121 is the Hughes specification for ESR 4340 and is included as Appendix B. The material then had to be machined into the various test sample sizes (3 inch diameter bars for the turning tests and various rectangular sizes for the other tests). After machining to test sizes, the material then had to be heat treated prior to testing. The heat treat process is a long one, involving normalizing, tempering and austenitizing in a vacuum furnace. The specific times and temperatures involved are presented in an excerpt from the Hughes Helicopters heat treatment specification, Appendix C. Due to the necessity of a vacuum furnace and the long time required, the heat treat process is a costly one. The difficulties incurred in obtaining acceptable ESR 4340 material for this program were increased due to the great and immediate demand required for the fabrication of actual YAH-64 parts.

The program required evaluation of material from two different heats in the turning operation. The other machining tests were to be conducted on material from the heat which was harder to turn. Some material from a previously purchased heat (No. 9087-4) was used for part of the turning tests. Heat treated hardnesses for this residual material did not meet minimum requirements. The specification called for 54-57 Rc, while the material could only reach 51-53 Rc hardnesses, even after re-heat treatment of the material. This was thought to be due to the fact that its carbon content was barely on the minimum end of the requirements. The material was still used in testing because of the difficulties in readily obtaining test material. It was also determined that the maximum thickness permitted for through-hardening was 3 inches. Thicker material resulted in a hardness reduction, not only in the core area, but towards the surface of the material as well. The bulk of the test material came from a newly purchased heat, No. 49103. This material was heat treated at Ironbound Inc., in New Jersey. Tensile specimens were heat treated along with the test material to verify the heat treatment. The mechanical properties of both transverse and longitudinal tensile specimens were found to meet minimum requirements. Hardness measurements taken on the new heat material indicate little hardness reduction, usually ranging about 54-55 Rc.

Initially, turning tests were conducted on 3 inch diameter bars from both the residual heat and the new heat. Using various carbide and ceramic inserts, determination of the best tool was made. For each tool, relations between cutting speeds, feeds, depths of cut and tool lives were analyzed in an attempt to establish the most efficient tool. A tool life limit of about 30 minutes was set for the turning tests due to limited amounts of material and time. The data obtained for turning is presented in Table II. Effects of cutting speeds on tool life for various carbide and ceramic inserts are illustrated in Figures 2 and 3. The feeds and speeds were rather low and tool lives quite short for the carbide inserts. At 0.050 inch depth of cut, the carbide grades generally had a tool life of less than 10 minutes for feeds of 0.005 inch and speeds greater than 150 fpm. Speeds lower than 150 fpm were generally not

TABLE II. DATA FROM TURNING (Heat 49103)

Insert	Cutting Speed (ft/min)	Feed (in./rev)	Depth of Cut (in.)	Tool Life (min:sec)
Carboloy 514	175	0.005	0.050	1:50
	150	0.005	0.050	9:00
Carboloy 545	175	0.005	0.050	10:36
	150	0.005	0.050	26:40
Carboloy 350	250	0.005	0.050	0:42
	200	0.005	0.050	6:24
	175	0.005	0.050	12:55
	150	0.005	0.050	0.004" wear @ 30:00
	125	0.005	0.050	0.002" wear @ 10:00
Carboloy 883	250	0.005	0.050	1:50
	225	0.005	0.050	5:00
	200	0.005	0.050	5:00
	175	0.005	0.050	7:10, 7, 3:10
	150	0.005	0.050	8:30
	125	0.005	0.050	10:00
B & W Ceramic	1000	0.005	0.050	0:21
	800	0.005	0.050	1:08
	800	0.0025	0.050	1:00
	700	0.005	0.050	1:09
	600	0.005	0.050	2:37
NPC-A Ceramic	1000	0.005	0.050	0:22
	800	0.005	0.050	0:50, 3:50
	800	0.0025	0.050	9:14
	700	0.005	0.050	1:25
	600	0.005	0.050	1:32
Sandvik 315	250	0.005	0.050	0:10
	175	0.005	0.050	2:40
	150	0.005	0.050	3:20
Kendex K-090 Ceramic	500	0.005	0.050	21:00
	525	0.005	0.050	34:00
	550	0.005	0.050	1:55

TABLE II. DATA FROM TURNING (Heat 9087) (CONT)

Insert	Cutting Speed (ft/min)	Feed (in. /rev)	Depth of Cut (in.)	Tool Life (min:sec)
Carboloy 883	100	0.010	0.100	22:00
	175	0.005	0.050	7:10
Carboloy 350	175	0.005	0.050	30:00
Carboloy 545	175	0.005	0.050	30:00
NPC-A Ceramic	1000	0.005	0.050	4:00
	900	0.005	0.050	0:24
	800	0.005	0.050	0:25
	500	0.005	0.050	2:51
	600	0.0025	0.050	25:45
B&W Ceramic	1000	0.005	0.050	0:37
	900	0.005	0.050	1:00
	800	0.005	0.050	2:26
Kendex K-090 Ceramic	500	0.005	0.050	29:16
	550	0.005	0.050	8:22
	600	0.005	0.050	2:18, 4:10

Tool geometry for all turning inserts as follows:

Back Rake: -5° SCEA: 15° Side Relief: 5°
Side Rake: -5° ECEA: 15° End Relief: 5°

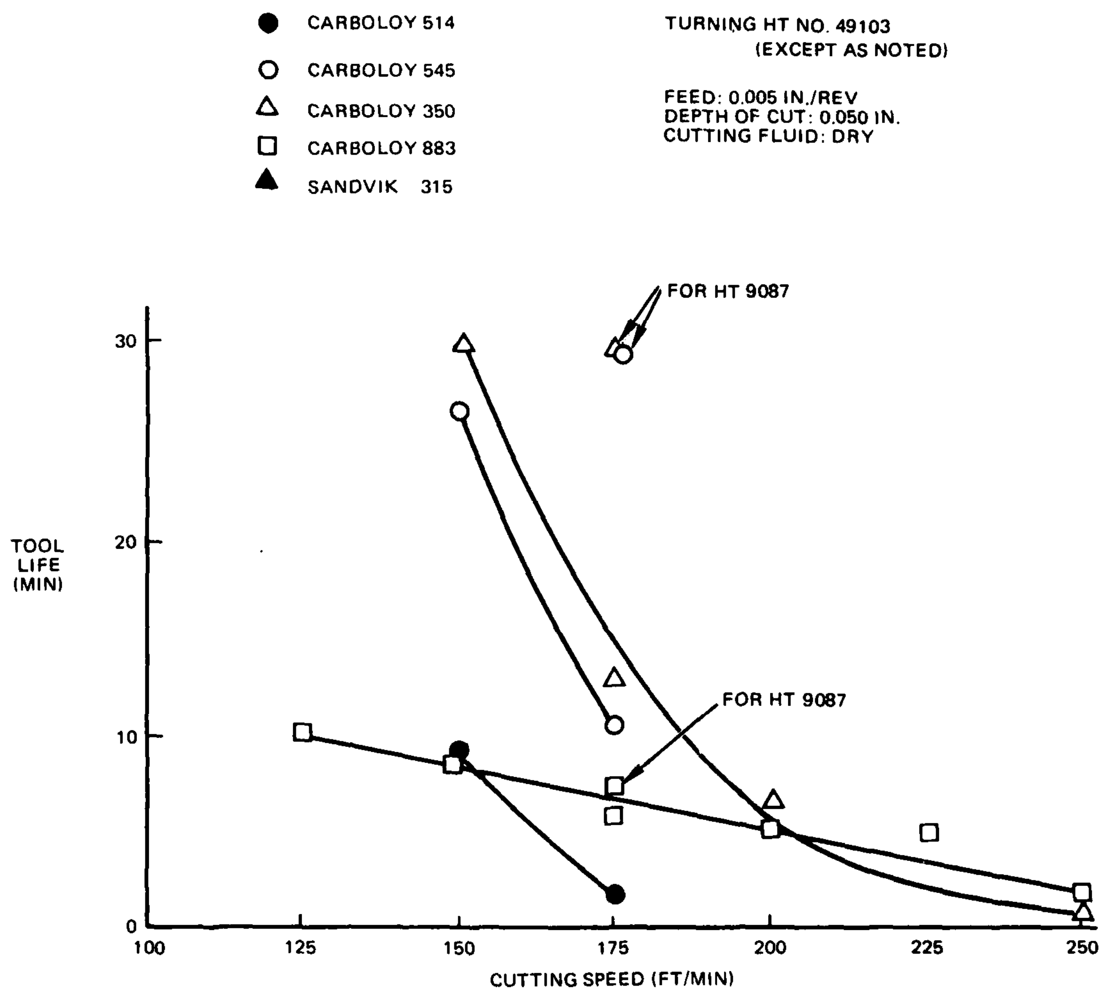
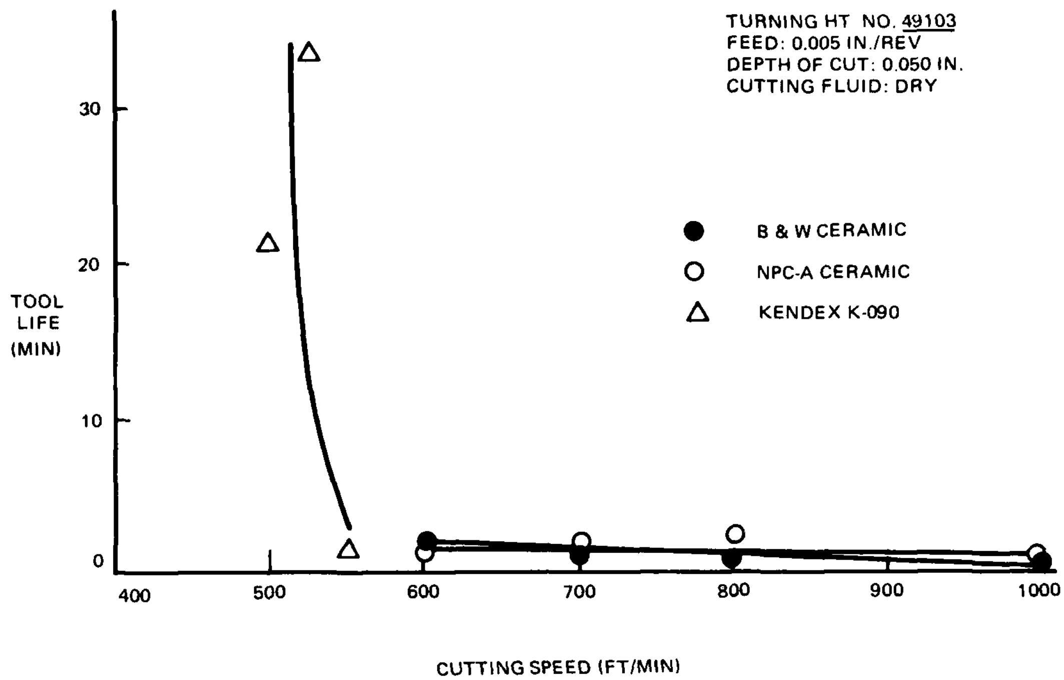


Figure 2. Effect of Cutting Speed and Tool Material (Carbide Inserts)



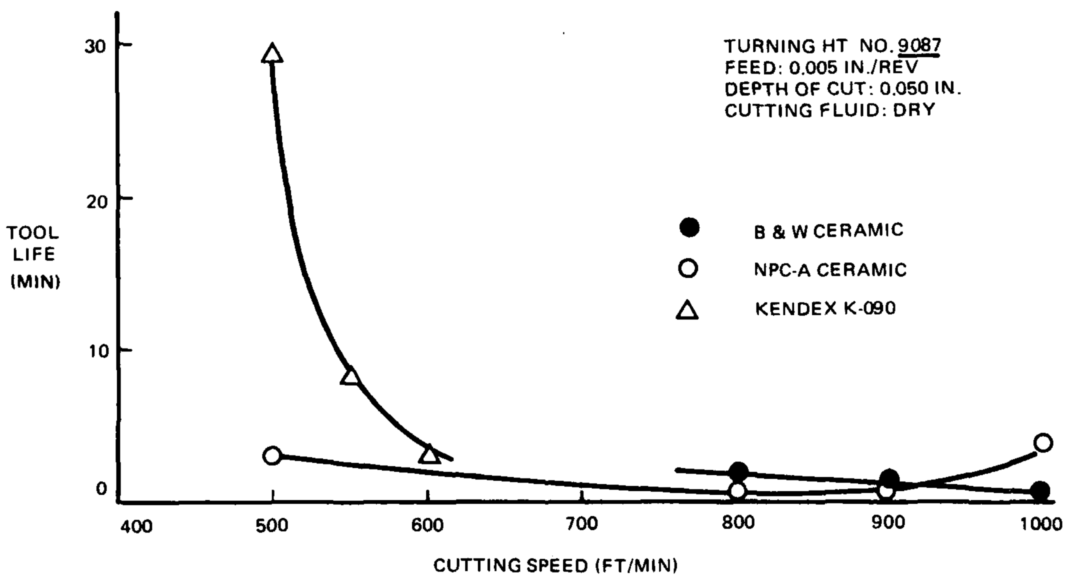


Figure 3. Effect of Cutting Speed and Tool Material (Ceramic Inserts)

tested due to its impracticality. The lower hardness of the residual heat material (Ht. 9087) seemed to make a great deal of difference regarding the life of the tool, in many cases doubling the tool life which was obtained when machining material from the other heat. A better picture of tool life variance due to insert types can be obtained by comparing the effects of turning material from heat No. 49103. Of the carbide inserts used for this heat, the Carboloy 545 and 350 grades seemed to perform the best. The 545 is an aluminum oxide coated, complex tungsten carbide insert used for finish machining. The 350 is an uncoated complex tungsten carbide insert used for light to medium roughing. Both have excellent resistance to high temperature crater and deformation. Ceramic inserts were expected to give better results, but chipping problems abruptly ended the tests after a few minutes. Speeds of 600 fpm and greater were used for these inserts. Another grade of ceramic, Kennametal Kendex K-090, was obtained in an attempt to eliminate chipping. Using lower cutting speeds, ~500 feet/minute, we were able to extend tool life up to approximately 30 minutes. The data obtained for the Kendex K-090 insert for Ht. 49103 is erratic. However, from the similarities of both heats involving the other ceramic inserts and the considerable improvements in tool life displayed by the K-090 in both heats, it is assumed that the curves are indicative of performance. The tool life end point was regarded as 0.015 inch wearland. This Kendex K-090 ceramic insert provided the best performance of all the tools tested.

Drilling was the next operation evaluated, using material from the new heat. The data obtained for drilling is presented in Table III. The study was limited to a single drilling diameter of 1/4 inch. Initially, various high speed steel and carbide drills were evaluated at various cutting speeds as low as 5 and 10 feet/minute and as high as 80 feet/minute. Using values of 0.001 ipr feed, 1/2 inch through depth of cut, with soluble and sulfurized oils, a determination of tool life was made. The results were very poor, with no more than 3 holes drilled per tool and a norm of 1 hole being drilled per tool. Attempts were made to obtain some T-15 drills, but a source could not be located. Chlorinated cutting fluid was obtained and appears to be of some benefit in drilling. The M-42 H.S.S. crankshaft point was used with the chlorinated oils to obtain additional data. Some of the effects of speeds and feeds using the M-42 drill is illustrated in Figure 4. Using very low cutting speeds of 5-15 feet/minute, and feeds of 0.0005-0.001 inches/revolution, drilling of multiple holes (~10/tool) was found to be possible. A tool life of 34 holes was obtained using a speed of 5 feet/minute and a feed of 0.0008 inches/revolution. As in turning, the tool life end point was regarded as 0.015 inch wear.

Face milling tests were conducted next, with an initial evaluation of various inserts. All of the information obtained is presented in Table IV. Figure 5 compares the various tools (including the Carmet CA310 which was

TABLE III. DRILLING

Tools	Cutting Speed (ft./min.)	Feed (in./rev.)	Depth of Cut (in.)	Cutting Fluid	Tool Life No. of Holes
High Speed Steel	10	0.001	1/2	Soluble Oil	0
High Speed Steel Crankshaft	5	0.001	1/2	Sulfurized Oil	3
Carbide	10	0.001	1/2	Soluble Oil	1
	80	0.0005	1/2	Sulfurized Oil	1, 1, 1, 1
	80	0.001	1/2	Sulfurized Oil	1
M-42	25	0.001	1/2	Soluble Oil	1
H.S.S.	10	0.001	1/2	Soluble Oil	3
Crankshaft	10	0.001	1/2	Soluble Oil	1
	10	0.0005	1/2	Soluble Oil	2
	5	0.001	1/2	Soluble Oil	2
M-42 H.S.S.	5	0.0008	1/2	Chlorinated Oil	34
Crankshaft	5	0.002	1/2		10
	5	0.005	1/2		2
	8	0.0005	1/2		10
	10	0.0008	1/2		7
	10	0.001	1/2		11
	10	0.002	1/2		1
	15	0.0005	1/2		6
	15	0.0008	1/2	Chlorinated Oil	3

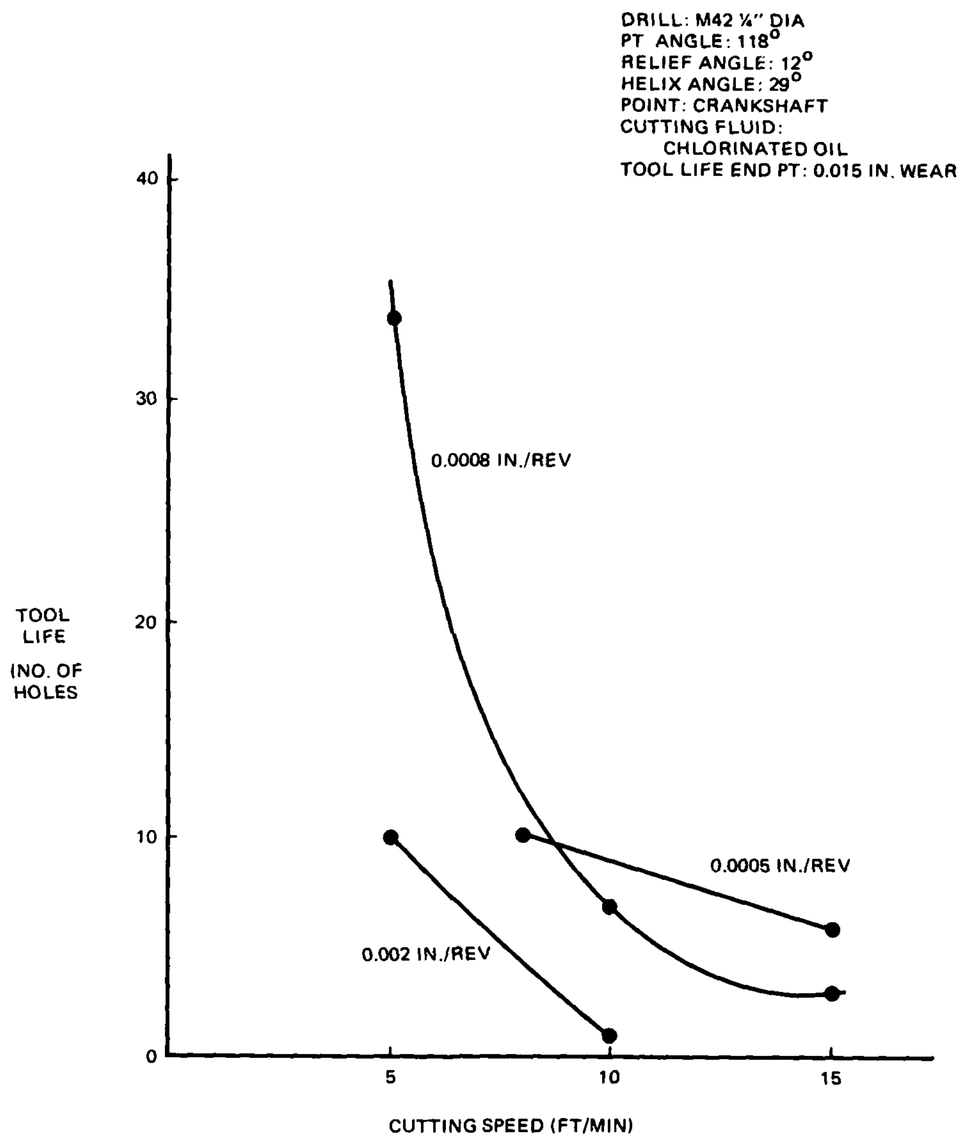


Figure 4. Effect of Cutting Speeds and Feeds in Drilling Using M42 H.S.S. Crankshaft Drill

TABLE IV. FACE MILLING DATA

Machining conditions constant for all tests below.
Depth of Cut = 0.060"
Width of Cut = 1 1/2"
Tool Life End Point: 0.015" wear

Insert	Cutting Speed ft./min	Feed in./tooth	Cutting Fluid	Tool Life Inches of Work Traveled
	Carbide			
Sandvik	125	0.005	Dry	2 1/2"
315	150	0.003	Dry	4"
Kennametal				
K-11	150	0.003	Dry	20"
K7H	150	0.003	Dry	2"
KC810	125	0.005	Dry	2 1/2"
Carboloy				
210	150	0.003	Dry	1"
370	150	0.003	Dry	11"
545	125	0.005	Dry	1"
883	40	0.005	Dry	10"
	60	0.005	Dry	12 1/2"
	75	0.005	Dry	8", 12"
	100	0.003	Dry	24"
	125	0.005	Dry	12"
	125	0.0015	Dry	19"
	125	0.003	Dry	29"
	150	0.003	Dry	36"
	150 (0.030" depth)	0.003	Dry	36"
	150 (0.090" depth)	0.003	Dry	28"
	150	0.003	Soluble Oil	6 1/2"
	200	0.003	Dry	15 1/2"
999	150	0.003	Dry	4"
Carmet	75	0.0085	Dry	54"
CA310	100	0.0085	Dry	60"
	100	0.003	Dry	32"
	100	0.005	Dry	41"
	100	0.007	Dry	56"
	100	0.010	Dry	48"
	125	0.0085	Dry	24"
	150	0.003	Dry	24"
	Ceramic			
Kennametal				
K060	125	0.005	Dry	1"
K090	125	0.005	Dry	7", 9-3/4"
	150	0.003	Dry	5 1/2", 10 1/2"
	175	0.003	Dry	10 1/2"

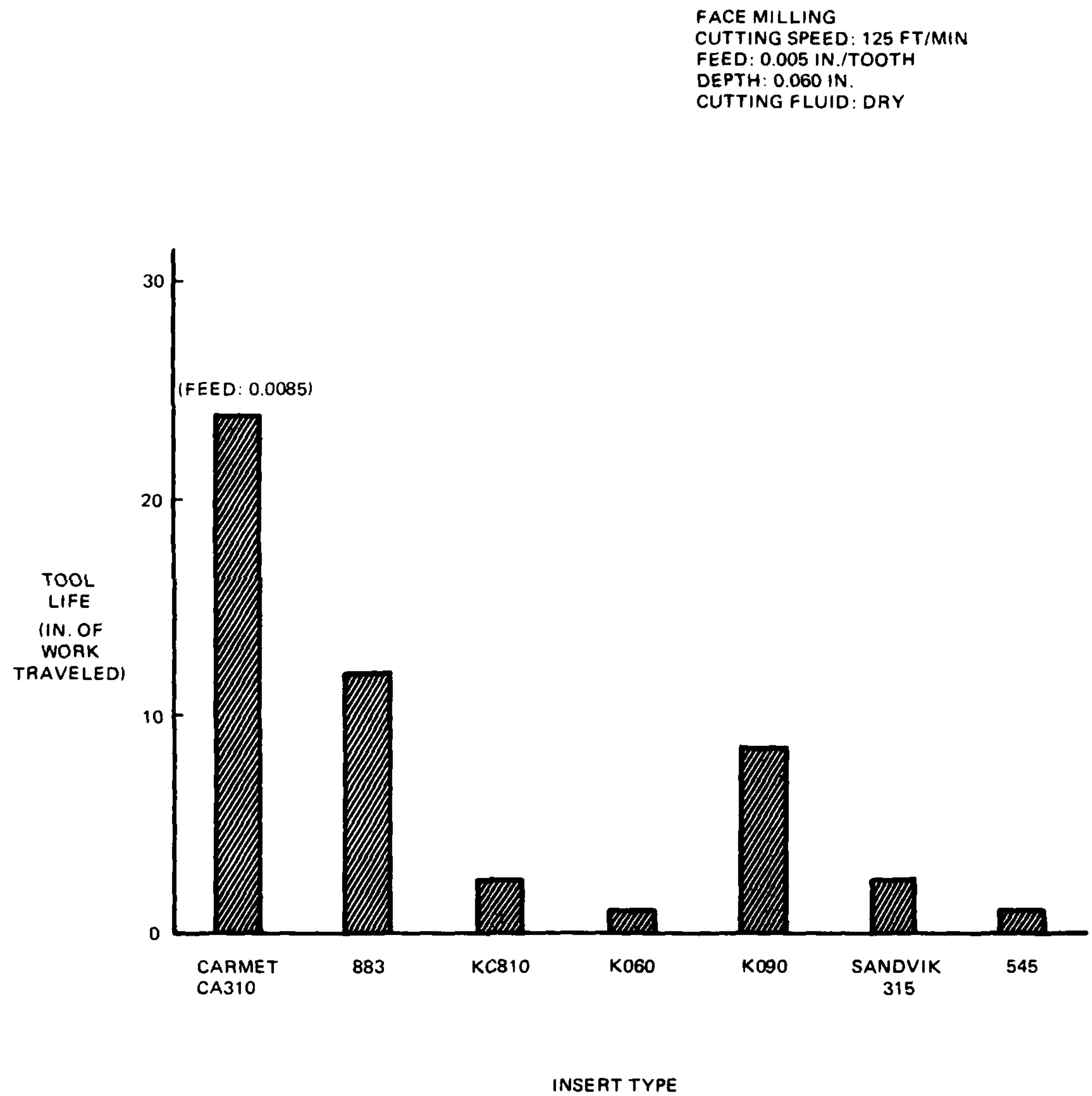
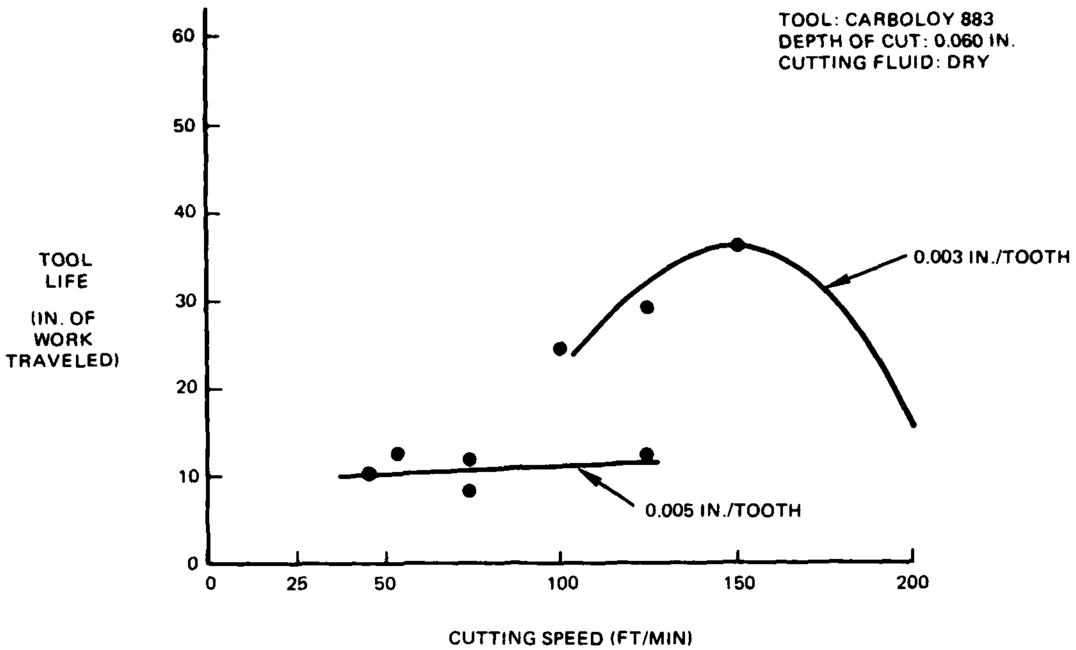


Figure 5. Comparison of Tools for Face Milling

obtained later) under like conditions. Of the tools initially evaluated, the Carboloy 883 insert appeared to perform the best. Effects of cutting speeds, feeds, and depths of cut were evaluated using this insert (Figure 6). It was determined that for this insert, a speed of 150 feet/minute and a feed of 0.003 inch/tooth was optimum. Also depths of cut higher than 0.060 inch seemed to result in a reduction of tool life, while lower depths of cut did not seem to produce much improvement. Another type of insert, a Carmet CA 310 was later obtained and tested. This micrograin carbide insert has the ability to withstand great impact and proved to be the best face milling tool tested. Figure 7 illustrates the effects of various parameters upon the performance of the CA 310 insert. Using greater feeds, but lesser speeds than the 883 carbide, tool lives of 40-60 inches of work traveled were obtainable with the Carmet insert. This is in comparison to the typical values of 10-30 inches obtained using the 883 insert. For the Carmet insert, a speed of 100 feet/minute and a feed of 0.0085 inch/tooth seemed to be optimum, using a 0.060 inch depth of cut. Some tests were attempted using cutting fluid but better results were obtained when the tests were run dry.

Peripheral end milling tests were run using various brazed on carbide end mills and insert type end mills. The data obtained with these tools is presented in Tables V and VI. A comparison of the tools tested is shown in Figure 8. Union, Rito and TRW end mills had brazed helical carbides while the 370 tool was brazed with a straight 370 carbide insert with no helix angle. These brazed end mills were all four-fluted. Ramet, 370 and 883 insert type end mills with equivalent geometries were tested. The insert types were all three fluted. The TRW was found to be the best of the brazed on type and the Ramet was found to be the best of the insert type. At a cutting speed of 100 feet/minute, a feed of 0.003 inch/tooth, a depth of cut of 0.060 inches, and a width of cut of 0.375 inches, both the Ramet and TRW tools had a tool life of 156 inches traveled. Though the tool life values for both of these tools were similar, the TRW tool had a higher removal rate due to the four-fluted nature of the tool. Again, better results were obtained without using a cutting fluid.

Finally, various grinding tests were conducted on the material. A study was made using low stress grinding techniques, and also using maximum and minimum values of two Hughes Helicopters process specifications, HP 18-12 and HP 15-51. The surface grinding conditions used are given in Table I of Appendix D. Figure 5 of Appendix D presents measured residual stress profiles from the surface to a depth of 0.0020 inches. Low level compressive stress, beneficial in fatigue, is present, along and just below the surface. Microhardness measurements taken at various distances from the surface illustrate the degree of surface degradation occurring for each condition.



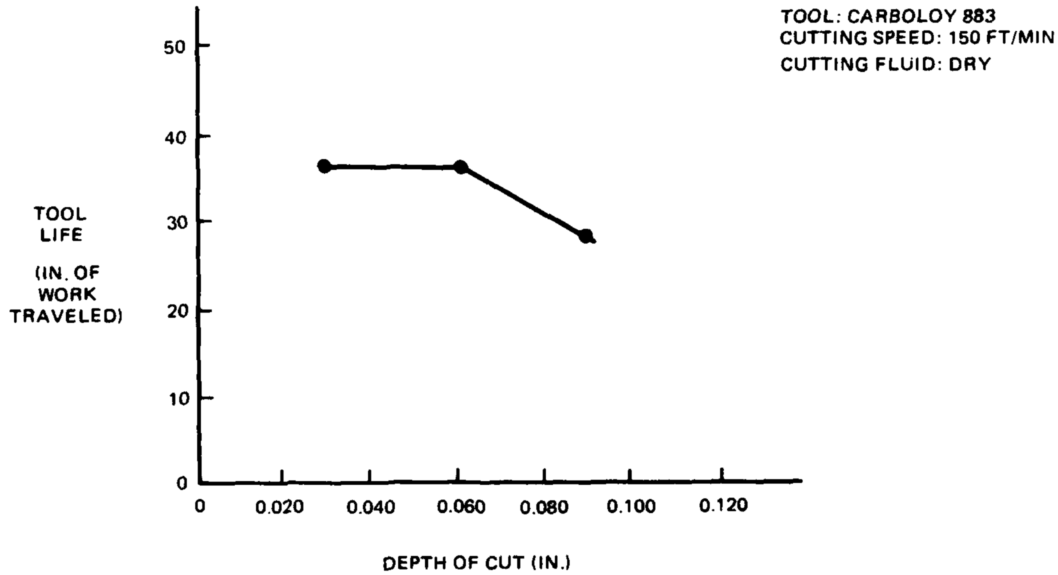


Figure 6. Effect of Parameter Variations in Face Milling with 883 Insert

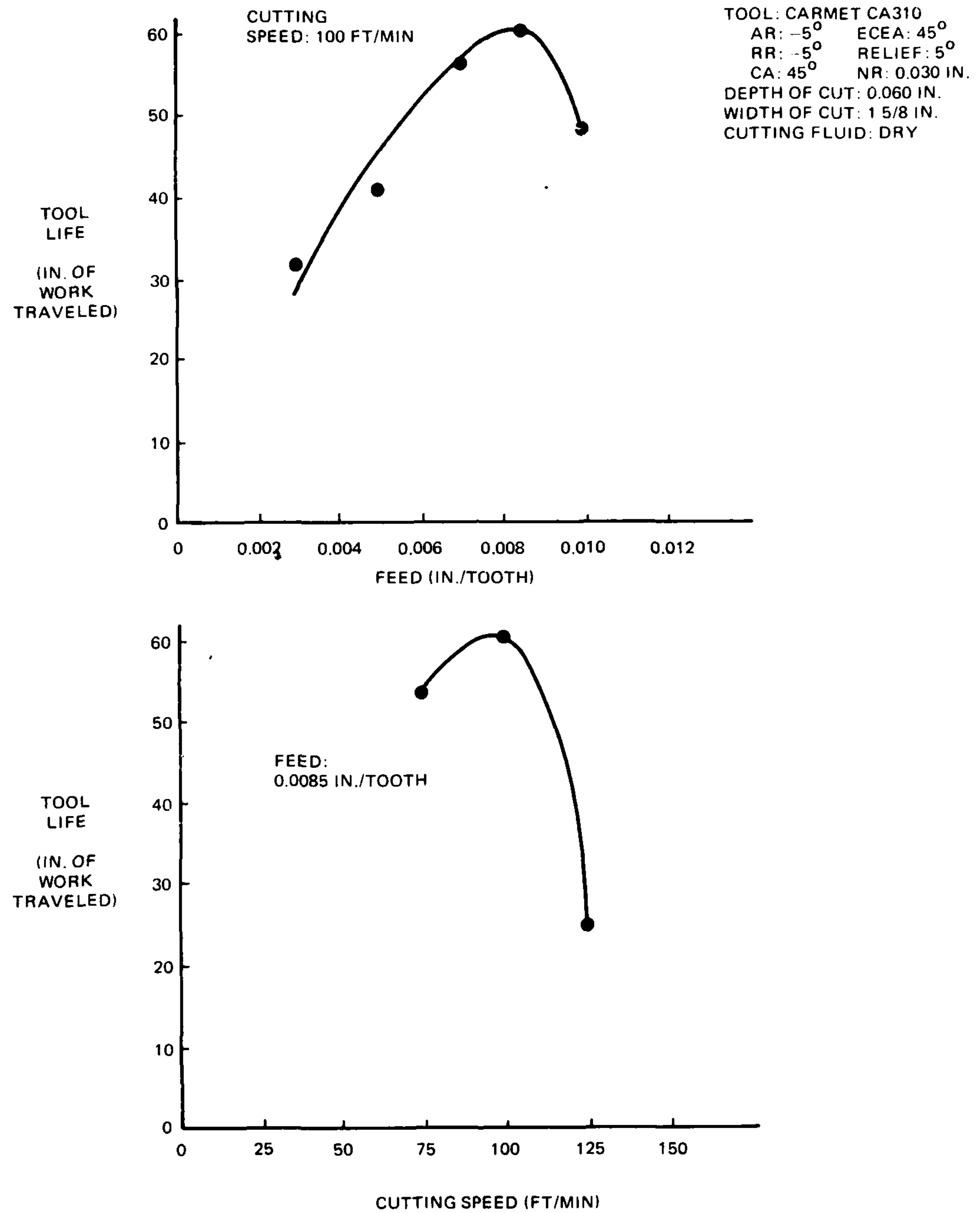


Figure 7. Effect of Parameter Variations in Face Milling with CA 310 Insert

TABLE V. PERIPHERAL END MILLING DATA

Brazed on carbide end mill geometry.

	Union	Rito	TRW	370
Axial Rake:	20°	20°	7°	0°
Radial Rake:	5°	5°	5°	-5°
Corner Angle:	45°	45°	45°	45°
End Cutting Edge Angle:	1°	1°	1°	1°
Per. Cl.:	10°	10°	10°	10°
End Cl.:	3°	3°	3°	3°

Cutting Tool	Cutting Speed ft./min.	Feed in./tooth	Depth of Cut in.	Width of Cut in.	Cutting Fluid	Tool Life in Work Traveled
			Brazed on			
Union	100	0.002	0.060	0.375	Dry	84"
Rito	100	0.002	0.060	0.375	Dry	60"
Trw	100	0.002	0.060	0.375	Dry	180"
	100	0.003	0.060	0.375	Dry	156"
370	75	0.002	0.060	0.375	Dry	48"
	100	0.001	0.060	0.375	Dry	108"
	100	0.001	0.060	0.375	Sol. Oil	48"
	100	0.002	0.060	0.375	Dry	132"
	100	0.003	0.060	0.375	Dry	108"
	125	0.002	0.060	0.375	Dry	120"

TABLE VI. PERIPHERAL END MILLING DATA

Geometry of Insert End Mills.

Axial Rake:	0°
Radial Rake:	5°
Corner Angle:	45°
End Cutting Edge Angle:	45°
Per. Cl.:	5°
End Cl.:	5°

Insert	Cutting Speed ft./min.	Feed in./tooth	Depth of Cut in.	Width of Cut in.	Cutting Fluid	Tool Life In. Work Traveled
Ramet	100	0.002	0.060	0.375	Dry	132
	100	0.003	0.060	0.375	Dry	156
370	100	0.002	0.060	0.375	Dry	72
	100	0.003	0.060	0.375	Dry	48
883	100	0.002	0.060	0.375	Dry	82
	100	0.003	0.060	0.375	Dry	72

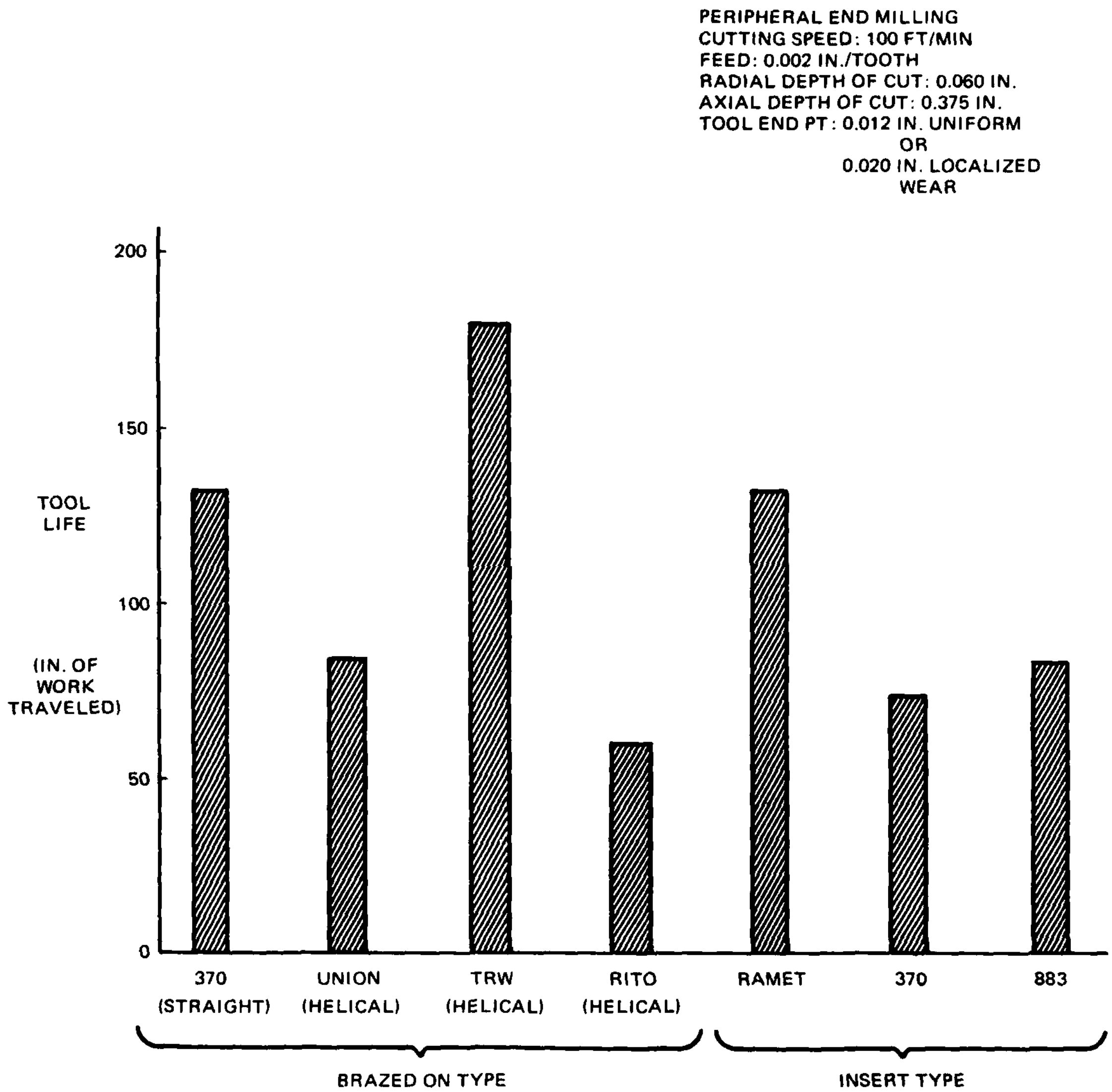


Figure 8. Comparison of Tools for Peripheral End Milling

This is illustrated in Figure 4 of Appendix D. Note that the greatest adverse effect takes place for HP 15-51 maximum. Detrimental surface tensile stresses occur for this condition and the photomicrograph (Figure 3 of Appendix D) indicates the extent of subsurface alterations. Photomicrographs (Figures 1, 2 and 3 of Appendix D) of the other conditions seem to show a generally smooth surface with a thin layer (0.0001 inch) of untempered martensite, and slight surface lapping and cracking.

The information obtained in this program, along with previously published data, indicate that certain modifications should be considered in the low stress grinding specification for ESR 4340 steel, HP 18-12 (Appendix E). The tests run by Metcut have verified the credibility of HP 18-12. However, certain variables such as crossfeeds and infeeds could be reduced to insure surface quality. Greater crossfeeds apply greater loads to the wheel, thereby increasing the probability of grinding burns. It is suggested that the crossfeed rate be reduced from 0.100 in./pass to 0.050 in./pass. The infeed rate is very important to surface integrity. It is suggested that a lower removal rate (0.0005 in./pass) be taken closer to the finish (0.002 in.) for rough grinding. Best finishing results are obtained at 0.0002 in./pass for such high strength steels.

Cutting fluids are also very important in low stress grinding. A sulfurized oil is best suited for this process. Oil based types include neutral fluids which do not give as much aid to the cutting process as a sulfurized oil. However, most machine stops have a certain cutting fluid generally used throughout the shop and changing this requirement in all shops would be difficult and impractical. It is suggested that sulfurized oil be mentioned in the specification as a recommended alternate to be used in low stress grinding procedures whenever possible.

From Metcut's past experiences, it was felt that an accurate definition of grinding wheel and dressing procedure was very important for achieving efficiency in grinding. A typical dressing procedure used for low stress grinding was to make 5 passes at 0.001 inch depth/pass with 2 sparkouts. The diamond traverse rate was 1 inch/7 seconds. It is suggested that this dress procedure be included as a part of the low stress grinding specification. A faster rate and greater depth of pass results in a rougher surface and increased diamond abuse. Slow rates with multiple shallow passes create maximum stress concentrations, although a smoother wheel is attained. The proper dressing procedure is one which utilizes the fastest rates while still maintaining an acceptable degree of surface roughness.

Under the scope of this program and with the amount of available material, an attempt was made to obtain the most comprehensive information possible regarding the conventional machining of ESR 4340 steel. All the machining operations were found to be extremely difficult and application towards production parts appears to be unfeasible. Reduced feeds and speeds still resulted in tool lives which were shorter than desired. Low stress grinding techniques do appear to be applicable to this material. Efforts are being made to incorporate the recommended changes to the low stress grinding specification. The extent of actual changes will be determined by the compromising effects of reduced production rates and increased quality.
Table VII summarizes the results obtained, presenting the best tools and conditions for each of the machining operations investigated in this program. In view of the results, the program has been cancelled and studies regarding possible alternative methods for machining ESR 4340 steel are being considered for a new program.

TABLE VII. OPTIMUM CONDITIONS FOR MACHINING ESR 4340 STEEL

Operation	Tool	Cutting Speed	Feed	Depth of Cut	Width of Cut	Cutting Fluid
Turning	Kendex K-090 Ceramic	500 Ft/Min	0.050 In./Rev	0.005 In.		Dry
	Tool Geom.:	Back Rake: -5° Side Rake: -5°	SCEA: 15° ECEA: 15°	Side Relief: 5° End Relief: 5°		
Drilling (1/4 In. Dia)	M-42 H.S.S. Crankshaft Pt.	5 Ft/Min	0.0008 In./ Rev.	1/2 In. Through		Chlorinated Oil
	Tool Geom.:	Pt. Angle: 118° Relief Angle: 112°	Helix Angle: 29°			
Face Milling	Carmet CA 310	100 Ft/Min	0.0085 In./ Tooth	0.060 In.	1 5/8 In.	Dry
	Tool Geom:	Axial Rake: -5° Radial Rake: -5°	ECEA: 45° Relief: 5°	Corner angle: 45°		
Peripheral End Milling	TRW Helical Brazed-On Carbide	100 Ft/Min	0.002 In./ Tooth	0.060 In.	0.375	Dry
	Tool Geom:	Axial Rake: 7° Radial Rake: 5°	ECEA: 1° Corner Angle: 45°	Per. Cl.: 10° End Cl.: 3°		
Surface Grinding (Low Stress)	Wheel Grade:	A46 HV				
	Wheel Speed:	2000 Ft/Min				
	Work Speed:	40 Ft/Min				
	Cross Feed:	0.050 In./Pass				
	Fluid:	Sulfurized Oil				
	Downfeed:	0.0005 In./Pass to 0.002 In. of Finish 0.0002 In./Pass Finish Grinding				
	Wheel Dress Procedure:	5 Passes @ 0.001 In./Pass 2 Sparkouts				
	Diamond Traverse Rate:	1 In./7 Sec				

CONCLUSIONS AND RECOMMENDATIONS

This study regarding the machining of ESR 4340 has led to the following conclusions:

- Conventional machining methods are not applicable to this material. Tool lives remain short despite reductions in feeds and speeds. Material removal rates are lower than those which can be used for other high strength steels.

- In ranges above 50 Rc, slight hardness reductions create great improvements in machinability, occasionally allowing tool lives to double.

- Turning and milling operations generally gave the best results when machining was done without cutting fluid. Drilling was aided by the use of chlorinated cutting fluid, while grinding was best done with sulfurized oil.

- Low stress grinding techniques are applicable to this material, when proper dressing procedures and reduced rates are used. The results of this program indicate the need to revise the low stress grinding specification for ESR 4340 steel regarding dressing procedure, cutting fluids and cutting rates.

Based on the results of the program studies of alternative methods of machining ESR steel is recommended. Although not used during the course of this program, previous studies indicate that Borozon (cubic boron nitride) wheels should be considered for surface grinding operations. They are highly resistant to wear and allow higher grinding speeds for greater productivity. However, the wheels are extremely high priced, often more than ten times the cost of equivalent aluminum oxide wheels. The Borozon wheel is best suited for grinding situations which occur repeatedly.

APPENDIX A

A compilation of data obtained primarily through a literature survey conducted at the Machinability Data Center. The data consists of conditions used in attempts to machine various high hardness materials (50 Rc and above) which approach ESR 4340 steel. The information was used to help establish a starting point for tools and parameter values in our own machining investigations involving ESR 4340 steel.

TURNING WITH CARBIDE AND HIGH SPEED STEEL TOOLS

Material	Hardness Rc	Condition	Depth of Cut (in)	Tool Material	Speed (fpm)	Feed (ipr)	Back Rake (deg)	Side Rake (deg)	Relief	*ECEA	SCEA	N.R.	Cutting Fluid	Tool Life, (min.)	Wearland (in.)
--	63-65	-	.008	S95	80	.003	-	-	-	-	-	-	Dry	-	-
EKh12M Steel	60-61	Q/T	.020	T15K6	66	.003	-18	0	10	15	15	0	Dry	-	-
EKh12M Steel	60-61	Q/T	.020	T15K6	55	.005	-18	0	10	15	15	0	Dry	-	-
EKh12M Steel	60-61	Q/T	.020	T15K6	43	.008	-18	0	10	15	15	0	Dry	-	-
EKh12M Steel	60-61	Q/T	.020	T15K6	36	.012	-18	0	10	15	15	0	Dry	-	-
EKh12M Steel	58-59	Q/T	.010	T15K6	75.5	.003	-23	0	10	15	15	0	Dry	-	-
EKh12M Steel	58-59	Q/T	.010	T15K6	66	.005	-23	0	10	15	15	0	Dry	-	-
EKh12M Steel	58-59	Q/T	.010	T15K6	49	.008	-23	0	10	15	15	0	Dry	-	-
EKh12M Steel	58-59	Q/T	.010	T15K6	36	.012	-23	0	10	15	15	0	Dry	-	-
D6ac	57	-	.060	C4	75	.005	-	-	-	-	-	-	-	13	-
440C	57	Q/T	.062	C2	95	.005	- 7	0	5	45	45	.030	Sol Oil (1:20)	30	.015
440C	57	Q/T	.062	C2	110	.005	- 7	0	5	45	45	.030	Sol Oil (1:20)	10	.015
440C	57	Q/T	.062	C6	50	.005	- 7	0	5	45	45	.030	Sol Oil (1:20)	28	.015
440C	57	Q/T	.062	C6	65	.005	- 7	0	5	45	45	.030	Sol Oil (1:20)	10	.015
300M (HSS)	56	Q/T	.062	T15	10	.005	0	10	5	5	15	.030	Sol Oil (1:20)	60	.060
300M (HSS)	56	Q/T	.062	T15	15	.005	0	10	5	5	15	.030	Sol Oil (1:20)	28	.060
300M (HSS)	56	Q/T	.062	T15	20	.005	0	10	5	5	15	.030	Sol Oil (1:20)	10	.060
300M (HSS)	56	Q/T	.062	M42	10	.007	0	10	5	5	15	.030	Sol Oil (1:20)	90	.060
300M (HSS)	56	Q/T	.062	M42	15	.007	0	10	5	5	15	.030	Sol Oil (1:20)	30	.060
300M (HSS)	56	Q/T	.062	M42	20	.007	0	10	5	5	15	.030	Sol Oil (1:20)	30	.060
300M Carbide	56	Q/T	.062	C7(K7H)	125	.005	- 5	- 5	5	15	15	.030	Dry	30	.015
300M (Carbide)	56	Q/T	.062	C7(K7H)	175	.005	- 5	- 5	5	15	15	.030	Dry	30	.015
300M (Carbide)	56	Q/T	.062	C7(K7H)	200	.005	- 8	- 5	5	45	15	.030	Dry	60	.008
300M (Carbide)	56	Q/T	.062	C7(K7H)	250	.005	- 8	- 5	5	45	15	.030	Dry	30	.015
300M (Carbide)	56	Q/T	.062	C7(K7H)	300	.005	- 8	- 5	5	45	15	.030	Dry	12½	.015
4340	54	-	.120	C6	90	.004	-	-	-	-	-	-	-	19	-
Vasco Jet 1000	54	-	.050	C7(350)	100	.0105	- 8	- 1½	6	20	15	1/8	Dry	140	.015
Vasco Jet 1000	54	-	.050	C7(350)	170	.0105	- 8	- 1½	6	20	15	1/8	Dry	60	.015
4340 (HSS)	53	Q/T	.050	370	200	.005	- 5	- 5	5	15	15	.030	Dry	17½	.015
4340 (HSS)	50-53	Q/T	.040	HSS	24	.007			----FLAT----				Sol Oil (1:20)	-	-

TURNING WITH CARBIDE AND HIGH SPEED STEEL TOOLS (cont.)

Material	Hardness Rc	Condition	Depth of Cut (in)	Tool Material	Speed (fpm)	Feed (ipr)	Back Rake (deg)	Side Rake (deg)	Relief	ECEA	SCEA	N.R.	Cutting Fluid	Tool Life (min.)	Wearland (in.)
4340 (HSS)	50-53	Q/T	.002	HSS	32	------------	------------	------------	FLAT	------------	------------	------------	Tapping CPD	-	-
4340	53	Q/T	.050	KSCBD	110	.005	- 5	- 5	5	15	15	.030	Dry	25	.015
4340	53	Q/T	.050	KSCBD	150	.005	- 5	- 5	5	15	15	.032	Dry	15	.015
4340	53	Q/T	.050	K165 TiC	150	.005	- 5	- 5	5	15	15	.032	Dry	41	.002
4340	53	Q/T	.050	K165 TiC	175	.005	- 5	- 5	5	15	15	.032	Dry	6-14	.015
4340	53	Q/T	.050	370	210	.005	- 5	- 5	5	15	15	.030	Dry	47	.016
4340	53	Q/T	.050	370	175	.005	- 5	- 5	5	15	15	.030	Dry	10	.016
4340	53	Q/T	.062	Rex 49 HSS	51	.009	3	6	10	10	10	.030	Dry	55	-
4340	53	Q/T	.062	Rex 49 HSS	35	.009	3	6	10	10	10	.030	Dry	36	-
Vasco Jet 1000	52	Q/T	.100	C8	100	.009	- 5	- 5	5	15	15	.030	Dry	50	.016
Vasco Jet 1000	52	Q/T	.100	C8	200	.009	- 5	- 5	5	15	15	.030	Dry	10	.016
Vasco Jet 1000	52	Q/T	.060	T15 HSS	20	.009	0	15	5	5	0	-	Highly Sul Oil	53	.060
4340	52	Q/T	.100	C8	150	.009	- 5	- 5	5	15	15	.030	Dry	47	.016
4340	52	Q/T	.100	C8	300	.009	- 5	- 5	5	15	15	.030	Dry	10	.016
4340	52	Q/T	.050	300 Carbal	125	.010	0	0	7	15	15	.032	Dry	100	.015
4340	52	Q/T	.050	350 Carbal	150	.010	0	0	7	15	15	.032	Dry	55	.015
4340	52	Q/T	.060	T15	25	.009	0	15	5	5	0	-	Sol Oil (1:20)	65	.060
4340	52	Q/T	.050	C6	230	.0105	- 1	8	6	15	15	1/32	Dry	10	.015
4340	52	Q/T	.050	C6	135	.0105	- 1	8	6	15	15	1/32	Dry	60	.015
4340	52	Q/T	.050	C6	120	.0105	- 5	- 5	-	-	-	-	Dry	10	.013
4340	52	Q/T	.050	C6	93	.0105	- 5	- 5	-	-	-	-	Dry	30	.015
4340	52	Q/T	.050	350 Carbal	250	.010	0	0	7	15	15	.032	Dry	10	.015
4340	52	Q/T	.050	C5	150	.009	- 5	- 5	-	15	15	1/32	Dry	90	.015
4340	52	Q/T	.050	C5	200	.009	- 5	- 5	-	15	15	1/32	Dry	37	.015
4340	52	Q/T	.050	C5	250	.009	- 5	- 5	-	15	15	1/32	Dry	8	.015
4340	52	Q/T	.100	C8	200	.009	- 5	- 5	5	15	15	.032	Dry	30	.015
4340	52	Q/T	.100	C8	250	.009	- 5	- 5	5	15	15	.032	Dry	15	.015
4340	52	Q/T	.100	C8	290	.009	- 5	- 5	5	15	15	.032	Dry	10	.013
6407	52	Q/T	1/8-3/16	-	191	.016	-	-	-	-	-	-	-	40	-

TURNING WITH CARBIDE AND HIGH SPEED STEEL TOOLS (cont)

Material	Hardness R_c	Condition	Depth of Cut (in)	Tool Material	Speed (fpm)	Feed (ipr)	Back Rake (deg)	Side Rake (deg)	Relief*	ECEA	SCEA	N.R.	Cutting Fluid	Tool Life (min.)	Wearland (in.)
HP 9-4-45(HSS)	51	Martemp	.062	M42	60	.005	0	10	5	15	15	.030	Sol Oil (1:20)	85	.015
HP 9-4-45(HSS)	51	Martemp	.062	M42	65	.005	0	10	5	15	15	.030	Sol Oil (1:20)	17½	.060
HP 9-4-45(HSS)	51	Martemp	.062	M2	60	.005	0	10	5	15	15	.030	Sol Oil (1:20)	50	.060
HP 9-4-45(HSS)	51	Martemp	.062	M2	65	.005	0	10	5	15	15	.030	Sol Oil (1:20)	20	.060
HP 9-4-45(HSS)	51	Martemp	.062	C8(K7H)	300	.007	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	24	.015
HP 9-4-45(HSS)	51	Martemp	.062	C8(K7H)	335	.007	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	10	.015
HP 9-4-45(HSS)	51	Martemp	.062	C8(K7H)	375	.007	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	5	.015
HP 9-4-45(HSS)	51	Martemp	.062	C6(370)	200	.007	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	20	.015
HP 9-4-45(HSS)	51	Martemp	.062	C6(370)	250	.007	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	7½	.015
HP 9-4-45(HSS)	51	Martemp	.062	C8(K7H)	300	.010	- 5	- 5	5	15	15	.030	Sol Oil (1:20)	9	.015
H11	50	-	.050	350 Carbal	175	.010	0	0	7	15	15	.032	Dry	100	.015
H11	50	-	.050	350 Carbal	200	.010	0	0	7	15	15	.032	Dry	38	.015
H11	50	-	.050	350 Carbal	250	.010	0	0	7	15	15	.032	Dry	10	.015
H11	50	-	.050	350 Carbal	290	.010	0	0	7	15	15	.032	Dry	5	.015
4340	50	Q/T	.062	C7(K7H)	300	.005	- 5	- 5	5	15	15	.030	Dry	37	.015
4340	50	Q/T	.062	C7(K7H)	400	.005	- 5	- 5	5	15	15	.030	Dry	12	.015
4340	50	Q/T	.062	C7(K7H)	500	.005	- 5	- 5	5	15	15	.030	Dry	7	.015
4340	50	Q/T	.062	523	275	.005	- 5	- 5	5	15	15	.030	Dry	12	.015
4340	50	Q/T	.062	523	350	.005	- 5	- 5	5	15	15	.030	Dry	10	.015
4340	50	Q/T	.062	C6(370)	200	.005	- 5	- 5	5	15	15	.030	Dry	27	.015
4340	50	Q/T	.062	C6(370)	250	.005	- 5	- 5	5	15	15	.030	Dry	15	.015
4340	50	Q/T	.062	XL-88	275	.005	- 5	- 5	5	15	15	.030	Dry	25	.015
4340	50	Q/T	.062	516	200	.005	- 5	- 5	5	15	15	.030	Dry	60	.015
4340 OESR	28/35	Normalized	.125	TNMG-432 Sandvik GC1025	110	.004	-	-	-	-	-	-	Trim Sol (20:1)	-	-
4340 OESR	28/35	Normalized	.200	TNMG-432 Ceratip 30	150	.004	-	-	-	-	-	-	Trim Sol (20:1)	-	-

TURNING WITH CERAMIC TOOLS

Material	Hardness R_c	Condition	Depth of Cut (in)	Tool Material	Speed (fpm)	Feed (ipr)	Back Rake (deg)	Side Rake (deg)	Relief	*ECEA	SCEA	N.R.	Cutting Fluid	Tool Life (min.)	Wearland (in.)
300M	56	Q/T	.020	SNG432	600	.002	- 5	- 5	5	15	15	.030	Dry	30	.015
300M	56	Q/T	.030	SNG432	600	.001	- 5	- 5	5	15	15	.030	Dry	30	.015
300M	56	Q/T	.030	SNG432	600	.001	- 5	- 5	5	15	15	.030	Dry	60	.010
300M	56	Q/T	.010	SNG432	600	.002	- 5	- 5	5	15	15	.030	Dry	60	.011
4340	53	280-300 ksi	.013-.050	Baxton DBA	235	.009	TNG-332							-	-
4340	54.5	-	.050	95% HfN 5% ZrB2	300	.005	- 5	- 5	5	15	15	1/16	Dry	1/2	.015
4340	53	Q/T	.030	0-30	340	.005	- 5	- 5	5	15	15	.045	Dry	10	.015
4340	53	Q/T	.050	0-30	315	.005	- 5	- 5	5	15	15	.045	Dry	40	.015
4340	53	Q/T	.050	CCT-707	540	.005	- 5	- 5	5	15	15	.045	Dry	10	.015
4340	53	Q/T	.050	CCT-707	400	.005	- 5	- 5	5	15	15	.045	Dry	28	.015
4340	53	Q/T	.050	60 TaN 40 ZrB2	770	.005	- 5	- 5	5	15	15	.045	Dry	10	.015
4340	53	Q/T	.050	60 TaN 40 ZrB_2	600	.005	- 5	- 5	5	15	15	.045	Dry	36	.015
4340	53	Q/T	.050	0-30	325	.005	- 5	- 5	5	15	15	.045	Dry	39	.015
4340	53	Q/T	.050	0-30	335	.005	- 5	- 5	5	15	15	.045	Dry	29	.015
4340	53	Q/T	.050	0-30	350	.005	- 5	- 5	5	15	15	.045	Dry	8½	.015
4340	53	Q/T	.050	60 TaN 40 ZrB_2	700	.005	- 5	- 5	5	15	15	.045	Dry	17	.015
4340	53	Q/T	.050	60 TaN 40 ZrB_2	800	.005	- 5	- 5	5	15	15	.045	Dry	7	.015
6407	52	-	1/8-3/16	0-30	464	.0115	TBT-124 P4							23½	-
6407	52	-	.015	0-30	544	.0115	TBT-123 P4							15½	-
4340	52	-	.050	Hf	550	.005	- 5	- 5	5	15	15	.030	Dry	35	.015
4340	52	Q/T	.050	40 Ta-10Mo	600	.005	- 5	- 5	5	15	15	.030	Dry	19	.015
4340	52	Q/T	.050	Nitrided	700	.005	- 5	- 5	5	15	15	.030	Dry	15	.015
4340	52	Q/T	.050	Hf-30Ta	600	.005	- 5	- 5	5	15	15	.030	Dry	50	.015
4340	52	Q/T	.050	SW-0113B	700	.005	- 5	- 5	5	15	15	.030	Dry	22	.015
4340	52	Q/T	.050	Nitrided	800	.005	- 5	- 5	5	15	15	.030	Dry	11	.015
4340	52	Q/T	.050	Nitrided	670	.005	- 5	- 5	5	15	15	.030	Dry	30	.015
6145	50-51	Q/T	.010	0-30	500	.0075	TATR; TB-123 P2						Dry	-	.010
4340	50	Q/T	.062	0-30	700	.005	- 5	- 5	5	15	15	.030	Dry	31	.015
4340	50	Q/T	.062	0-30	750	.005	- 5	- 5	5	15	15	.030	Dry	25	.015
4340	50	Q/T	.062	0-30	800	.005	- 5	- 5	5	15	15	.030	Dry	12	.015
4340	50	Q/T	.062	Act 1	700	.005	- 5	- 5	5	15	15	.030	Dry	18	.015
4340	50	Q/T	.062	C06	600	.005	- 5	- 5	5	15	15	.030	Dry	40	.015
4340	50	Q/T	.062	AMA 68	600	.005	- 5	- 5	5	15	15	.030	Dry	23	.015
4340	50	Q/T	.062	DBA	600	.005	- 5	- 5	5	15	15	.030	Dry	15	.015
4340	50	Q/T	.062	707	600	.005	- 5	- 5	5	15	15	.030	Dry	60	.015
4340	50	Q/T	.062	C06	600	.005	- 5	- 5	5	15	15	.030	Dry	40	.015

TURNING WITH CERAMIC TOOLS (cont.)

Material	Hardness R_c	Condition	Depth of Cut (in)	Tool Material	Speed (fpm)	Feed (ipr)	Back Rake (deg)	Side Rake (deg)	Relief	*ECEA	SCEA	N.R.	Cutting Fluid	Tool Life (min.)	Wearland (in.)
521100 Rolls	68	Hardened	.045	BZN	275	.022	- 5	- 5	5	-	-	-	Sol Oil (1:20)	120	-
Steel Forging	65	Hardened	1/32-1/8	Baxton DBA	52-81	.006	RNG-43							25	-
Steel Forging	65	Hardened	1/32-1/8	Baxton DBA	150	.010	RNG-43							15	-
52100	63	Q/T	.100	VR-97	225	.008	- 5	- 5	-	-	30	1/16	Dry	5	.010
52100	63	Q/T	.100	VR-97	250	.004	- 5	- 5	-	-	30	1/16	Dry	5	.010
52100	63	Q/T	.100	VR-97	250	.008	- 5	- 5	-	-	30	1/16	Dry	5	.010
52100	63	Q/T	.100	VR-97	550	.004	- 5	- 5	-	-	30	1/16	Dry	5	.010
52100	63-60	Q/T	.015	0-30	600	.005	0	0	5	15	60	11/32	Dry	15	-
52100	63-60	Q/T	.015	0-30	400	.005	0	0	5	15	60	11/32	Dry	63	-
1118	62-65	Q/T	.010	0-30	1050	.0065	-25	-25	-	-	-	3/16	Dry	-	-
5000	60-62	-	-	SQT163 PO	600	.005	-25	-25	-	-	-	-	Dry	-	-
Mill Rolls	60-62	-	1/32	VR-97	340	.008	HIGH LEAD ANGLE						Dry	30+	.001
Alloy Steel	60	Carb.	.015	0-30	80	.0105	TDTL-85							9	-
Alloy Steel	60	Carb.	.0025	0-30	80	.0105	TDTL-85							9	-
Alloy Steel	60	Carb.	.013/.018	0-30	115	.0105	TDTR-85							6.5	-
Solid Forged	60	-	-	C06	280	.0025	-10	-	-	20	20	1/16	-	-	-
440C	57	Q/T	.062	CCT-707	200	.005	- 7	0	5	45	45	.045	Dry	26	.015
440C	57	Q/T	.062	CCT-707	225	.005	- 7	0	5	45	45	.045	Dry	7½	.015
D6ac	56	Q/T	.050	CCT-707	200	.005	- 5	- 5	5	15	15	.045	Dry	10	.015
D6ac	56	Q/T	.050	CCT-707	110	.005	- 5	- 5	5	15	15	.045	Dry	35	.015
D6ac	56	Q/T	.050	CCT-707	215	.005	- 5	- 5	5	15	45	.045	Dry	10	.015
D6ac	56	Q/T	.050	CCT-707	150	.005	- 5	- 5	5	15	15	.045	Dry	47	.015
D6ac	56	Q/T	.050	0-30	280	.005	- 5	- 5	5	15	15	.045	Dry	10	.015
D6ac	56	Q/T	.050	0-30	200	.005	- 5	- 5	5	15	15	.045	Dry	36	.015
D6ac	56	Q/T	.050	60Tan-40ZrB$_2$	580	.005	- 7	0	5	45	45	.045	Dry	10	.015
D6ac	56	Q/T	.050	CCT-707	300	.005	- 7	0	5	45	45	.045	Dry	28	.015
D6ac	56	Q/T	.050	CCT-707	150	.005	- 7	0	5	45	45	.045	Dry	47	.015
D6ac	56	Q/T	.050	CCT-707	200	.005	- 7	0	5	45	45	.045	Dry	19	.015
D6ac	56	Q/T	.050	CCT-707	250	.005	- 7	0	5	45	45	.045	Dry	2-1/3	.015
300M	56	Q/T	.062	Baxton DBA	325	.005	- 8	- 5	5	45	45	.030	Dry	35	.015
300M	56	Q/T	.062	Baxton DBA	375	.005	- 8	- 5	5	45	45	.030	Dry	27	.015
300M	56	Q/T	.010	Act I	550	.003	- 5	- 5	5	15	15	.030	Dry	27	.015
300M	56	Q/T	.010	Act I	650	.003	- 5	- 5	5	15	15	.030	Dry	11	.015
300M	56	Q/T	.010	Act 1	700	.003	- 5	- 5	5	15	15	.030	Dry	6	.015
300M	56	Q/T	.010	C06	600	.003	- 5	- 5	5	15	15	.030	Dry	30	.015
300M	56	Q/T	.010	VR-97	600	.001	- 5	- 5	5	15	15	.030	Dry	30	.015

DRILLING

Material	Hardness	Cond.	Drill Dia.	Tool Mat'l.	Speed FPM	Feed IRP	Point Ang.	Relief	Chisel Edge Ang.	Helix Ang.	Point Grind	Cutting Fluid
Thermolds	50	Q/T	.250	M-33	20	.0035	135	-	100	12	-	Su-CL
Vasco Jet 1000	50	Q/T	.250	M-33	40	.001	118	7	-	29	Crk.	Su
Vasco Jet 1000	50	Q/T	.250	M-33	40	.0015	118	7	-	29	Crk.	Su
Vasco Jet 1000	50	Q/T	.250	M-33	40	.0015	118	7	-	29	Crk.	Su
4340	50	Q/T	.250	T-15	30	.001	118	7	-	29	Crk.	Su
4340	52	-	.250	T-15	20	.0005	90	7	-	29	Std.	Su-CL
4340	52	-	.250	T-15	40	.0005	90	7	-	29	Std.	Su-CL
4340	52	Q/T	.257	-	30	.001	135	5	-	12	Notch	CL
4340	52	Q/T	.257	-	40	.001	135	5	-	12	Notch	CL
4340	52	Q/T	.257	-	50	.001	135	5	-	12	Notch	CL
4340	52	Q/T	.250	M-33	30	.0006	135	-	110	12	Notch	Su-CL
4340	52	Q/T	.250	M-33	30	.0006	-	-	-	12	-	-
4340	52	Q/T	.250	T-15	30	.001	118	7	-	29	Crk.	Su
Vasco Jet 1000	52	Q/T	.250	M-33	40	.001	118	7	-	29	Crk.	Su
Vasco Jet 1000	52	Q/T	.250	M-33	40	.0015	118	7	-	29	Crk.	Su
4340	52	Q/T	.250	T-15	20	.001	118	7	-	29	Crk.	Su
4340	50/53	-	.250	T-15	15	.001	130	-	Chamfer	-	Std.	Su-CL
4150/4140	52/53	Q/T	.250	C-2	100	.001	118-135	7	130	29	Crk.	Su-CL
D6AC	54	Q/T	.250	M-33	40	.001	90	7	-	29	Crk.	Su
D6AC	54	Q/T	.250	M-33	50	.001	90	7	-	29	Crk.	Su
D6AC	54	Q/T	.250	M-33	60	.001	90	7	-	29	Crk.	Su
MX-2	54	Q/T	.250	M-33	45	.001	90	7	-	29	Crk.	Su
MX-2	54	Q/T	.250	M-33	50	.001	90	7	-	29	Crk.	Su
4340	54	Q/T	.250	C-2	27	.0015	-	-	-	-	-	Sol. Oil
98BV40	54	Q/T	.250	C-2	150	.001	118	12	-	20	Std.	CL
4340	55	Q/T	.250	-	90	.001	140	-	110	0	-	Sol. Oil
4340	55	Q/T	.250	T-15	30	.001	118	7	-	29	Crk.	Su
300M	55	Q/T	.250	T-15	15-20	.001	118	12	-	29	Std.	CL
300M	55	Q/T	.250	M-42	10	.0005	118	12	-	29	Crk.	CL-C
300M	55	Q/T	.250	C-2	140	.0005	118	12	-	29	Crk.	CL-C
300M	55	Q/T	.250	C-2	140	.001	118	12	-	29	Crk.	CL-O
4140/4150	54/56	Q/T	.250	C-2	75	.001	118-135	7	130	29	Crk.	Su-CL
D6A C	56	Q/T	.250	C-2	105	.001	-	-	-	-	-	CL
Thermol D J	57	Q/T	.250	M-33	90	.001	140	-	110	12	-	Sol. Oil
D6ac	57	Q/T	.250	C-2	105	.001	-	-	-	-	-	CL

TAPPING

Material	Hardness	Condition	Tap Dia. In.	Thds.	Flutes	Tap Mat'l.	% Thds.	Speed FPM	Hook Angle	Land Width	Flute Depth	Flute Rad.	Cutting Fluid
300M	55	Q/T	5/16	24NF	3	M42	75	5	-	-	-	-	CL
Dëac	54	Q/T	5/16	24NF	4	M10	75	5	0	.090	.072	.082	CL
4340	52	Q/T	5/16	24NF	4	-	58	70	-	.099	-	-	CL
4340	52	Q/T	5/16	18NC	4	60	5	-	-	-	-	-	CL
H-11	50	Q/T	1/4	20NC	-	HSS	60	6	15	-	-	-	Su
Vasco Jet 1000	50	Q/T	5/16	18NC	4	M10	60	5	-	-	-	-	CL
Vasco Jet 1000	50	Q/T	5/16	18NC	4	M10	60	5	-	-	-	-	-
Vasco Jet 1000	50	Q/T	5/16	18NC	4	M10	60	5	-	-	-	-	CL
4340	50	Q/T	1/4	20NC	-	HSS	60	10	7	-	-	-	Su
4340	50	Q/T	5/16	18NC	4	M10	60	5	-	-	-	-	CL

MILLING

Material	Hardness	Condition	Depth Cut	Tool Mat'l.	Speed FPM	Feed IPT	Axial Rake	Radial Rake	Ax. Rel.	Rad. Rel.	ECEA	Helix Angle	Corner Angle	Cutting Fluid	Tool Life min.	Wear Land in.
Cr-[illegible]	56	Hob	.119	VK6M	67	.0016	-	-15	-	15	-	-	-	Su	99	.01[illegible]
Drac	56	Face	.040	C2(883)	97	.006	0	-15	10	10	5	-	45	Dry	-	.016
Vasco Jet 1000	56	Face	.050	C2	173	.0057	-	-8	-	-	-	-	0	Dry	40	.015
300M	55	End	.060	C6(370)	500	.002	0	0	3	10	-	0	45	Dry	1400	.012
300M	55	End	.015	C6(370)	70	.002	0	0	3	10	-	0	45	Dry	-	.008
300M	55	End	.060	C6(370)	550	.002	0	0	3	10	-	-	-	Dry	600	.012
300M	55	End	.060	C6(370)	600	.002	0	0	3	10	-	0	45	Dry	300	.012
H-50	55	Face	.025	2%Cr_2C	2947	5	0	-45	4	4	-	-	-	CO_2	9	.006
H-50	55	Face	.100	6%TiC	175	3.75	-	0	3	2/10	-	-3	-	CO_2	4	.0035
H-50	55	Face	.100	6%TiC	175	3.75	-	0	3	2/10	-	-3	-	Sol. Oil	2.7	.006
H-50	55	Face	.075	6%TiC	175	3.75	-	0	3	2/10	-	-3	-	CO_2	13.5	.005
H-50	55	Face	.075	2%Cr_2C	153	2.87	-	0	3	2/10	-	-3	-	CO_2	14.2	.010
98BV40	54	Face	.060	C6	100	.002	-5	-5	5	5	45	-	45	Dry	160	.015
98BV40	54	End	.125	C6(370)	200	.001	-5	-5	5	5	-	-5	0	Dry	215	.012
98BV40	54	End	.125	C6(370)	300	.001	-5	-5	5	5	-	-5	0	Dry	125	.012
H-50	54	Rout	.025	6%TiC	1200	20	-3	0	3	2/10	45	-3	45	CO_2	175	.002
H-50	54	End	.025	6%TiC	1200	5	-3	0	3	2/10	45	-3	45	CO_2	1.3	.003
H-50	54	Slot	.025	6%TiC	1200	5	-3	0	3	2/10	45	-3	45	CO_2	2.6	.002
9KH	54	Hob	.020	VK8	70	.002	0	0	-	13	-	-	-	Dry	100	.008
4340	54	Face	.050	C-6	170	.0046	-	-	-	-	-	-	0	Dry	18	.015
40KH	53-60	Hob	-	VK6M	-	-	-	-	-	-	-	10	-	-	120-130	.01[illegible]
4340	52	Face	.100	C-6	150	.005	0	-15	8	8	5	-	45	Dry	60	.015
4340	52	Side	.100	C6(370)	150	.0075	-5	-10	6	8	5	-	45	Dry	60	.015
4340	52	Slot	.250	C-2	200	.005	-5	-10	3	8	1	-	45	Dry	35	.015
4340	52	End	.250	C-2(883)	50	.0015	0	0	5	15	3	35	45	Sol. Oil	78	.015
4340	52	End	.062	M-33	54	.002	-	-	-	-	-	-		Sol. Oil	250	.015
4340	52	End	.062	M-33	63	.002	-	-	-	-	-	-		Sol. Oil	160	.015
4340	52	End	.062	M-33	127	.002	-	-	-	-	-	-		Sol. Oil	96	.016
4340	52	Face	.100	C6(370)	180	.005	-0	-15	6	6	5	-	45	Dry	90	.015
4340	52	Face	.100	C6(370)	188	.005	0	-15	8	8	5	-	45	Dry	42	.015
4340	52	Face	-	C6(370)	180	.005	0	0	7	7	5	-	15	Dry	60	.015
4340	52	Face	-	C6(370)	425	.005	0	0	7	7	5	-	15	Dry	10	.015
Vasco Jet 1000	52	Face	.100	C-2	125	.005	0	-15	8	8	5	-	45	Dry	80	.015
Vasco Jet 1000	52	Side	.100	C-2	150	.0075	0	-15	8	8	5	-	45	Dry	60	.012
Vasco Jet 1000	52	Slot	.250	C-2	200	.005	-5	-10	8	8	1	-	45	Dry	50	.012
Vasco Jet 1000	52	End	.250	C-2(883)	60	.0015	0	0	5	15	3	-	45	Sol. Oil	105	.015

GRINDING

Surface Grinding

Material	Hardness	Wheel Speed (FPM)	Table or Work Speed	In Feed (in/pass) or Down Feed (in/rev)	Cross Feed (in/pass)	Wheel Grade	Cutting Fluid	Grinding Ratio	Grinding Condition
Alloy Steel	62-48	3000-3400	100-250	.0005 - .001	-	A46 H or G	Su - O	-	Rough
Alloy Steel	62-48	3000-3400	100-250	.0005 - .001	-	A80 H or G	Su - O	-	Finish
M-50	61	6000	40	.001	.050	32A46H8VBE	Su - O	10.8	Rough
M-50	61	4000	40	.0005	.050	32A46H8VBE	Su - O	7.4	Finish
Diac	57	6000	40	.001	-	A46H8V	Su - O	75	Conv.
Diac	56	6000	40	.001	.050	32A46H8VBE	Sol. Oil 120	-	Conv.
9-4-45 Martemp	51	6000	40	.001	.050	32A46K8VBE	Sol	45	Conv.
4340	50	2000	-	LS	-	A46HV	Su	-	L. S.
M-4	-	12 000	350	-	-	A80P4V	-	18	-

Cylindrical Grinding

Material	Hardness	Wheel Speed (FPM)	Table or Work Speed	In Feed (in/pass) or Down Feed (in/rev)	Cross Feed (in/pass)	Wheel Grade	Cutting Fluid	Grinding Ratio	Grinding Condition
Alloy Steel	65-48	4500-6000	70-100	.002	W/4	A60IV	Su	-	Rough
Alloy Steel	65-48	4500-6000	70-100	.0004	W/8	A60IV	Su	-	Finish
52100	62-60	7200	24	-	-	A220M14DIAXI	Su Su	96000 Parts	-
52100	61	8500	226	-	-	A80V9BC2ES	Su	-	-
Ductile Iron	60-53	5500-6500	70-100	.002	W/4	A60JV	-	-	Rough
Ductile Iron	60-53	5500-6500	70-100	.0005	W/8	A60JV	-	-	Finish
4145	53	6782	130	.00377	-	23A36MVBE	Int'l. 131(40:1)	19	Rough

Internal Grinding

Material	Hardness	Wheel Speed (FPM)	Table or Work Speed	In Feed (in/pass) or Down Feed (in/rev)	Cross Feed (in/pass)	Wheel Grade	Cutting Fluid	Grinding Ratio	Grinding Condition
52100	64	-	-	-	-	B180N100V	3% Sol Oil	-	-
SHKH15	62-61	9396	<156	.0003	-	A46SM-1	-	44	-
52100	62-60	5715	975	-	-	A80L6	Cimcol (50:1)	-	-
52100	60	9000	5	-	-	80LV	-	-	-
52100	60	9000	2.5	-	-	80TB	-	-	-
4150	55-50	7370	1186	-	-	60M6	-	-	-

GRINDING

Plunge Grinding

Material	Hardness	Wheel Speed (FPM)	Table or Work Speed	In Feed (in/pass) or Down Feed (in/rev)	Cross Feed (in/pass)	Wheel Grade	Cutting Fluid	Grinding Ratio	Grinding Condition
41450	55-53	6620	1218	-	-	4A60M6VL	Flowrex 100	-	-
41450	55-53	6620	1218	-	-	32A70M6VBE	Flowrex 100	-	-
T-15	55-53	6620	1218	-	-	4A60M6VL	Flowrex 100	-	-
Internal Plunge									
M-4	65	12000	250	0.004	.001	A60K4V	-	-	-
M-4	65-63	12200	250	-	.001	12A80P4V	-	-	-
52100	62-60	12000	250	.004	.001	A70K8V			
52100	62-60	7200	120	.003	-	A60L5V			
52100	62-60	7200	120	.003	-	A90P6V			

APPENDIX B

HMS 6-1121, Hughes material specification for electroslag refined 4340 steel forged billet.

Hughes Helicopters
division of Summa corporation

ENGINEERING ORDER

E.O. NO. 132148

MODEL	EFFECTIVE ON	E.O. TYPE	AUTHORITY
All	Next parts made	Material specification revision	MJO 0136
		PARTS MADE: MAY BE REWORKED / OK TO USE x / RECORD / NOTED	CCN/MOD

AFF. GROUP	SPECIFICATION AFFECTED NO. (YES [ ] NO [X])	ATP/FTP AFFECTED NO. (YES [ ] NO [ ])	INTERCHANGEABILITY AFFECTED (YES [ ] NO [X])	E.O. BY
				J. Preston

DOCUMENT	REV.	SIGNIFICANT CHANGE (YES [ ] NO [X])	GROUP	DATE
HMS 6-1121	F	Electroslag Refined 4340 Steel Forged Billet	18-10	09-20-78

NEXT ASSY.

REL. DATE	BY:
9-2[illegible]	[illegible]

DRAWING TO BE CHANGED YES [ ] NO [X]

APPROVED BY	DATE
PE 77 [illegible]	[illegible]
PE 369A KS C. [illegible]	20 Sept 78
STRESS [signature]	9-11-78
PE COMM'L [signature]	9-20-78
TECH. DEPT. [signature]	9-11-78
MAT'L & PROCESS J. C[illegible]	8-30-78
CHANGE CONT.	
CONF. CONT. [signature]	9/20/78
SPT. SERVICES	
MFG [signature]	9-20-78
PA [illegible]	9-20-78
SYSTEMS [signature]	9-20-78

COPIES TO

Sarlin[illegible] (7)

REFERENCED E.O.'S 126568, 130696, 130876, 131222, 131361, 131962

REASONS & REMARKS

E.O. NO. 132148

FORM 9022 REV. 2/74

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
New	Released on EO 126568	05/29/71	
A	Released on EO 130696	08/15/75	
B	Released on EO 130876	12/23/75	
C	Released on EO 131222	08/12/76	
D	Released on EO 131361	11/21/77	
E	Released on EO 131962	03/24/78	
F	Released on EO 132148	09/20/78	

SCOPE: This specification covers electroslag refined (ESR 4340) steel forged billet intended for use at the 280- to 300-ksi strength level.

CHANGES: (1) Editorial change to format.

(2) Maximum carbon content in Table I changed from 0.43 to 0.41.

(3) 3.10.1 adds new microinclusions requirements.

Change bars indicate technical changes only.

PREP	J E Ruston 8-24-78	**Hughes Helicopters** Division of Summa Corporation		Centinela and Teale Streets Culver City, California 90230	
APPD	J. C. Brunch / RHH	TITLE ELECTROSLAG REFINED 4340 STEEL FORGED BILLET			
9-11-78	J. M. McDermott				
9-11-78	W Blum M Vogel				
9-20-78	S M Carlson	SIZE A	CODE IDENT NO. 02731	NO. HMS 6-1121	REV. F
9-20-78	C Rondeau				
9-20-78	J W O'Brien F.M.			SHEET 1 of 11	

FORM 1642

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TITLE: ELECTROSLAG REFINED 4340 STEEL FORGED BILLET

1. SCOPE

1.1 This specification covers electroslag refined (ESR) 4340 forged billet intended for use at the 280- to 300-ksi strength level.

2. APPLICABLE DOCUMENTS

2.1 Government documents. The following documents of the exact issue in effect on date of the invitation for bids or request for proposal form a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, the requirements of this specification shall prevail.

SPECIFICATIONS

Military

MIL-I-8950	Inspection, Ultrasonic, Wrought Metals, Process for

STANDARDS

Federal

FED-STD-151	Federal Test Method

2.1.1 Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

2.2 Non-Government documents

SPECIFICATIONS

Industry

Hughes Helicopters

HP 1-1	Heat Treatment of Steels, Nickel-Base, and Cobalt-Base Alloys
HP 6-5	Magnetic Particle Inspection
HP 6-19	Hardness Testing of Metals
HP 6-22	Ultrasonic Inspection of Metals
HP 6-25	Procedure for Determining the Mechanical Properties of Metallic Materials
HP 8-5	Identification of Detail Parts and Assemblies

OTHER PUBLICATIONS

Aeronautical Materials Specifications

AMS 2300	Premium Aircraft Quality Steel Cleanliness - Magnetic Particle Inspection Procedures

American Society for Testing and Materials

ASTM E 45	Determining the Inclusion Content of Steel
ASTM E 122	Estimating the Average Grain Size of Metals
ASTM E 353	Chemical Analysis of Stainless Steel, Heat Resistant, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
ASTM E 381	Rating Macroetched Steel

2.2.1 Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.

3. REQUIREMENTS

3.1 Definitions.

3.1.1 AOD. Argon-oxygen decarburized.

3.1.2 ESR. Electroslag refined.

3.1.3 Ingot. A quantity of 4340 AOD or ESR steel melted in a single mold of a known size and weight.

3.1.4 Lot. A quantity of 4340 steel melted by the ESR process into an ingot and hot worked as a single unit to different product sizes and forms.

3.1.5 Melt. A homogeneous batch of 4340 AOD steel melted and solidified into ingot(s).

3.1.6 RCS. Round corner square.

3.2 Material quality.

3.2.1 The starting material shall be a single melt of 4340 argon-oxygen decarburized (AOD) ingot(s) or equivalent prior to remelting by the electroslag refining process.

3.2.2 The material shall be produced by the electroslag refining process using equipment specifically designed for electroslag refining of low-alloy, high-strength steels that has been approved for steel making by the Materials, Processes, and Standards Department of Hughes Helicopters.

3.2.3 The billet stock shall be hot worked in at least two longitudinal planes to ensure that minimum mechanical properties can be met in the transverse direction when heat treated and tempered to full strength level.

3.3 Forging temperature. The forging stock shall be heated to 2100° ±25°F (1149° ±13.9°C) for initial heating and shall receive a minimum reduction of 3:1 in cross section area. The finish forging temperature shall be within the range of 1700° to 1800°F (927° to 982°C).

3.4 Condition. Forged billet shall be supplied in the normalized and tempered condition in accordance with HP 1-1.

3.5 Composition. The lot shall conform to the percentages by weight shown in Table I.

TABLE I. COMPOSITION PERCENTAGES BY WEIGHT

Element	Minimum	Maximum
Carbon	0.38	0.41
Manganese	0.60	0.80
Silicon	0.20	0.35
Phosphorus	—	0.010
Sulfur	—	0.008
Chromium	0.70	0.90
Nickel	1.65	2.00
Molybdenum	0.20	0.30
Copper	—	0.35
Aluminum	—	0.030
Iron	—	balance

3.6 Macrostructure. Full cross-section macroslab wafer prepared in accordance with 4.2.3 shall be free of cracks, pipe, bursts, segregation, flakes, seams, and other deleterious effects which would adversely affect static mechanical properties after heat treat.

3.7 Mechanical properties. The material shall meet the minimum mechanical properties specified in Table II after heat treatment per HP 1-1 to the HT condition.

TABLE II. MINIMUM MECHANICAL PROPERTIES

Direction	Ftu ksi (MPa)	Fty ksi (MPa)	El Percent	R.A. Percent
Longitudinal	280 (2689)	200 (2275)	10	25
Transverse	260 (1793)	200 (1496)	10	25

3.8 Hardness. Material hardness tested in accordance with HP 6-19 shall meet the hardness requirements after heat treatment to the HT condition as follows:

a. Brinell Hardness, 535 to 578

b. Rockwell Hardness, Rc 54 to 57

3.9 Cleanliness. The product shall be uniform in quality and condition, clean, sound and free from foreign materials when magnetic particle inspected per 4.2.6.

3.10 Microexamination.

3.10.1 Microinclusions. The size and frequency of microinclusions shall not exceed the Jernkontoret limits as shown in Table III when tested per 4.2.7.

TABLE III. MICROINCLUSION RATING

Microinclusion Type	Dimensional Limitations Thickness or Diameter (inches)	Worst Field
Type A - thin	0.00016 max	1.5
Type A - heavy	0.00040 max	1.0
Type B - thin	0.0003 to 0.0005, excl	1.5
Type B - heavy	0.0005 to 0.0010, incl	1.0
Type C - thin	0.00020 max	1.5
Type C - heavy	0.00035 max	1.0
Type D - thin	0.0002 to 0.0004, excl	2.0
Type D - heavy	0.0004 to 0.0010, incl	1.5

Note: For Types A, B and C thin combined, there shall be not more than three fields of No. 1.5A type, or No. 1.5B and No. 1.0C types, and not more than five other lower rateable A, B and C type-thin fields per specimen. For D type-thin, there shall be not more than three No. 1.5 fields, and no more than five other lower rateable D type-thin fields per specimen. There shall be not more than one field each of No. 1.0A, B and C type or No. 1.5D type-heavy per specimen. A rateable field is defined as one which has a Type A, B, C or D microinclusion rating of at least No. 1.0 thin or heavy in accordance with the dimensional limitations and the Jernkontoret Chart.

3.10.2 Microstructure. The microstructure shall be predominatly tempered martensite after heat treatment to the HT condition.

3.10.3 Grain size. The austenitic grain size shall be 5 or finer.

3.11 Decarburization limits for forgings. Table IV defines acceptable limits for decarburization of as-forged products.

TABLE IV. DECARBURIZATION LIMITS FOR AS-FORGED PRODUCTS

Nominal Diameter or Distance Between Opposite Faces in. (mm)	Maximum Depth of Decarburization* in. (mm)
– to 0.375 (9.53)	0.010 (0.254)
0.376 to 0.500 (9.55 to 12.7)	0.012 (0.305)
0.501 to 0.625 (12.73 to 15.9)	0.014 (0.356)
0.626 to 1.000 (15.9 to 25.4)	0.017 (0.432)
1.010 to 1.500 (25.7 to 38.1)	0.020 (0.508)
1.510 to 2.000 (38.4 to 50.8)	0.025 (0.635)
2.010 to 2.500 (51.1 to 63.5)	0.030 (0.762)
2.510 to 3.000 (63.8 to 76.2)	0.035 (0.889)
Over 3.000 (76.2)	0.045 (1.143)

*The value specified as the maximum depth of decarburization is the sum of the complete, plus the partial decarburization.

Note: When determining the depth of decarburization, it is permissible to disregard local areas provided the decarburization of such areas does not exceed the limits of Table III by more than 0.005 inch (0.127mm) and the width is 0.065 inch (1.65mm) or less.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for testing.

4.1.1 Supplier responsibility. The supplier is responsible for the performance of all testing requirements as specified herein. The supplier may utilize his own facilities or any commercial testing laboratory acceptable to Materials, Processes, and Standards Department of Hughes Helicopters.

4.1.2 Hughes Helicopters. All incoming material shall be inspected upon receipt at Hughes Helicopters for compliance to the requirements specified herein. Each lot shall be tested. When more than one size of material is represented by a single lot, a sample from each of the following product sizes shall be tested.

2.5 to 3.5 RCS or dia, in.

4.5 to 5.5 RCS or dia, in.

8.0 to 10 RCS or dia, in.

Substitution or deviation from the above sizes shall be approved by HH Materials, Processes and Standards Department.

4.1.3 Process control documentation. Written procedures controlling fabrication, inspection, and testing of material shall be maintained by the supplier and shall be available for review by Hughes Helicopters.

4.2 Testing requirements.

4.2.1 Chemical analysis. Chemical composition shall be determined by wet chemical methods in accordance with ASTM E 353, by spectrographic methods in accordance with FED-STD-151, Method 112, or by other approved analytical methods.

4.2.2 Ultrasonic. Each forged billet shall exhibit an ultrasonic quality per MIL-I-8950, Class A, or HP 6-22, Class B, as applicable.

4.2.3 Macroexamination. A serialized full cross-section macroslab wafer approximately 1 inch thick shall be taken from the top and bottom of the largest forged billet. The wafer shall be ground to an RHR 63 finish, or better, and etched in a hydrochloric-sulfuric acid mixture per ASTM E 381.

4.2.4 Mechanical properties. The material shall meet the minimum mechanical properties specified in Table II after heat treatment to the HT condition per HP 1-1, and testing per HP 6-25. Longitudinal and transverse specimens shall be tested.

4.2.5 Hardness. Material shall be hardness tested per HP 6-19 and meet hardness requirements after heat treatment to the HT condition.

4.2.6 Magnetic particle inspection. Each lot shall be magnetic particle inspected in accordance with AMS 2300 or HP 6-5 using a stepped down test bar and shall meet the cleanliness requirements of 3.9.

4.2.7 Microexamination. A section of material taken in the longitudinal and transverse direction shall be examined for conformance to 3.10. Austenitic grain size shall be measured per ASTM E 122. The size and frequency of microinclusions shall be determined on a longitudinal section in accordance with ASTM E 45.

4.3 Reports.

4.3.1 The supplier shall furnish with each shipment three copies of a test report for each lot to determine conformance to the requirements of Section 3 of this specification.

4.3.2 Records. Copies of these test reports shall be filed for a minimum of 3 years after completion of the contract and shall be made available to Hughes Helicopters personnel upon demand.

4.4 Identification.

4.4.1 Unless otherwise specified, each forged billet shall be marked in accordance with the requirements of HP 8-5, Type I, Class 3 with HMS 6-1121, lot number, manufacturer's identification, ingot number, and nominal size in inches. The characters shall not be less than 3/8 inch (9.6 mm) in height.

4.5 Rejection and retests.

4.5.1 If any of the tests specified herein fails, the lot represented by the failed specimen shall be rejected and shall be submitted to Hughes Helicopters Material Review Board for disposition.

Where stock sizes are furnished that have been qualified by first article testing at HH the supplier will be required to requalify the material in the event that reforging operations have been performed.

5. PREPARATION FOR DELIVERY

5.1 Packaging. All material shall be properly separated by size, shape, and condition, and packaged in a manner acceptable to common carrier for safe transportation.

5.1.1 Shipping containers, crates, boxes, or bundles shall be marked to give the following information:

a. Material - ESR 4340 steel forged billet

b. Hughes Helicopters Material Specification (HMS) 6-1121

c. Condition - normalized and tempered

d. Size

e. Quality in this container

f. Purchase order number

g. Manufacturer's name or trademark

h. Lot number

6. NOTES

6.1 Intended use. The process covers an electroslag refined steel forged billet at a 280- to 300-ksi strength level used in the manufacture of helicopters and their ordnance.

7. APPROVED VENDORS

7.1 Vendors whose products are acceptable under this specification are listed in Hughes Helicopters' Approved Vendors List (AVL) 1121.

APPENDIX C

Excerpt from HP1-1, Hughes Helicopter's heat treatment specification for steel. The excerpt describes the heat treat process established for ESR 4340.

Table X. Heat Treatment of Special Steels

<u>4340 Electroslag Refined Steel (ESR) (See HMS 6-1121)</u>

Equipment - Normalize, temper (1175°F/635°C) and austenitize shall be performed in a vacuum furnace capable of meeting all of the requirements specified herein.

Condition NT - Normalize at 1650°F ±25°F (899° ±13.9°C) for 3 hours minimum at temperature per inch (2.54 cm) of thickness, and cool in inert atmosphere. Temper at 1175° ±25°F (635° ±13.9°C) for 3 hours per inch (2.54 cm) of thickness; air or furnace cool.

Condition HT - (Material must be in condition NT prior to heat treating to condition HT). Austenitize at 1525°F ±25°F (829° ±13.9°C) for 3 hours minimum at temperature per inch (2.54 cm) of thickness.

Oil quench (bath temperature after quenching not to exceed 140°F (60°C)).

Temper at 340°F ±10°F (171° ±5.6°C) for 4 hours.

Hardness - Material shall meet the hardness requirements as follows:

Condition NT - Brinell Hardness 277-321 (R_C28-35)

HT - Brinell Hardness 535-578 (R_C54-57)

Decarburization - Parts designated as "ballistic critical" shall be free of decarburization (total and partial). For fully hardened material intended for final use in non-ballistic applications, the depth of partial decarburization (complete decarburization not permitted) after all heat treat operations shall not exceed 0.003 inch (0.008 cm) on any surface.

After any grinding operation in the hardened condition, stress relief-275° ±10°F (135° ±5.6°C) for two hours minimum.

Table X. Heat Treatment of Special Steels (Cont)

Process Control - Each batch of parts shall include three tensile bars for each heat of material in the batch. The tensile bars shall be transverse, full sized (R1) per HS 101, and shall be of the same heat as the parts they represent. In the event that size and/or configuration of available material will not permit making full sized transverse tensile bars, the largest obtainable sub-sized transverse tensile bars, per HS 101, may be used. The tensile bars shall accompany the parts they represent through all cleaning and heat treating processes. The tensile bars shall be tested at a Hughes Helicopters approved testing facility and mechanical properties thus obtained shall conform to the requirements of HMS 6-1121.

APPENDIX D

Metcut report regarding surface grinding of ESR 4340 steel. An evaluation was made using low stress grinding techniques and also using maximum and minimum conditions of two Hughes Helicopters specifications. Studies of photomicrographs, hardnesses, and residual stress concentrations were conducted to determine the effects of the various conditions.

SURFACE GRINDING OF 4340 ESR STEEL

Metcut Report 1752-26887-2

for

Hughes Helicopter
Division Summa Corporation
Attn: Mr. Kenneth Niji
Building 305
Culver City, CA 90230

Purchase Order HH112976-737

March 13, 1980

John B. Kohls
John B. Kohls, Supervisor
Machinability Department

Metcut Research Associates Inc.
3980 Rosslyn Drive
Cincinnati, OH 45209

513/271-5100

At the request of Mr. Ken Niji of Hughes Helicopter, Metcut Research Associates performed various surface grinding test cuts on 4340 ESR steel. These test cuts were then compared using various metallographic techniques. The comparisons included 100X to 1000X visual examination, micro-hardness travers and residual stress profiles.

Metcut has performed extensive studies in the area of Surface Integrity. Surface integrity is a study of the surface quality of the workpiece after machining. This work includes both surface and subsurface alterations. As a result of this work, Metcut has developed grinding procedures that will produce a low level compressive stress that is beneficial in fatigue applications.

One of the five (5) conditions evaluated in this program is the technique mentioned above and is identified as "LSG". The remaining four (4) conditions were taken from Hughes Process Specifications supplied by Mr. Niji. The specifications supplied were HP 18-12 and HP 15-51.

The five (5) conditions evaluated are listed in Table I. For each condition, the various grinding parameters are listed in the table.

After machining, metallographic sections were removed from the samples in such a manner as to minimize heat induced by cut-off.

Sections were taken both longitudinal and transverse to the grinding lays.

After metallographic mounting, the sections were ground back approximately 0.060 inches using a low speed wheel and silicon carbide paper which was flushed continuously with water.

Samples were prepared using metallographic techniques that assure optimum edge retention.

Examination of the samples was performed at magnifications from 100X to 1000X with micro-sections in the etched and unetched condition.

Photomicrographs and microhardness values were obtained on samples prepared in the direction transverse to the grinding lay axis.

Figures 1, 2, and 3, are typical photomicrographs of the five test conditions. All surfaces are relatively smooth. The only surface showing excessive subsurface alteration is HP 15-51 Max. in Figure 3.

The microhardness traverse profiles are shown in Figure 4. Each condition shows some surface softening as a result of the grinding conditions. Condition HP 15-51 Max. again shows the most alteration from the core hardness values.

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Figure 5 is a graph of the residual stress profiles for each test surface. The only surface showing the detrimental tensile stresses is the HP 15-51 Max. A writeup on the residual stress technique and calculation is given immediately after Figure 5.

From this investigation, it seems that specifying the specification HP 18-12 can yield a fairly good level of surface quality. However specifying the specification HP 15-51 would not produce a similar effect. HP 15-51 depending on parameters selected, could yield either compressive or tensile stress. This wide variation in residual stress is not recommended for a high stressed critical part.

TABLE I

SURFACE GRINDING CONDITIONS 4340 ESR STEEL

Parameter	LSG	HP 18-12 Min.	HP 18-12 Max.	HP 15-51 Min.	HP 15-51 Max.
Wheel Speed, fpm	2000	2000	3500	2000	6000
Wheel Grade	A46HV	A60I	A60J	A46HV	A60J
Work Speed, fpm	40	40	80	30	60
Cross Feed, in./pass	.050	.050	.100	.100	.400
Fluid	Sulf Oil	Sulf Oil	Straight Oil	Polar Chip	Polar Chip
Depth of Grind, in.	.010	.010	.010	.010	.010
Down Feed	16 @ .0005	7 @ .0007	7 @ .0007	6 @ .001	6 @ .001
No. of Passes @ Depth/Pass	2 @ .0004	17 @ .0003	17 @ .0003	8 @ .0005	8 @ .0005
	6 @ .0002				
Dress Procedure					
No. of Passes @ Depth/Pass	5 @ .001	5 @ .001	5 @ .001	5 @ .001	5 @ .001
	2 Sparkouts	2 Sparkouts	2 @ .0005	2 Sparkouts	2 @ .0005
			5 @ .0002		5 @ .0002
			4 Sparkouts		4 Sparkouts
Diamond Traverse Rate	1 in./7 sec.	1 in./7 sec.	1 in./21 sec.	1 in./7 sec.	1 in./21 sec.

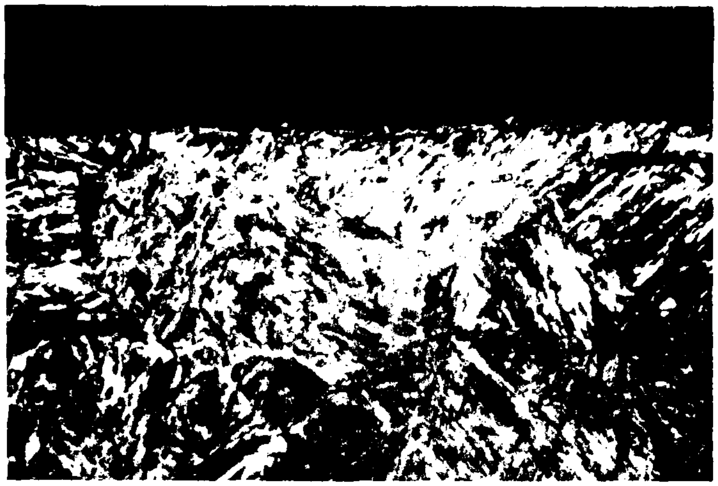
Mount No. 24257 1000X

Mount No. 24257 1000X

Generally Smooth Surface With Isolated Light Etching Scallops. No Evidence of Laps or Cracks.

PHOTOMICROGRAPHS OF 4340SR STEEL SURFACE GROUND BY METCUT "LOW STRESS" GRIND TECHNIQUES

Figure 1



Mount No. 24179 1000X
HP 18-12 Min.

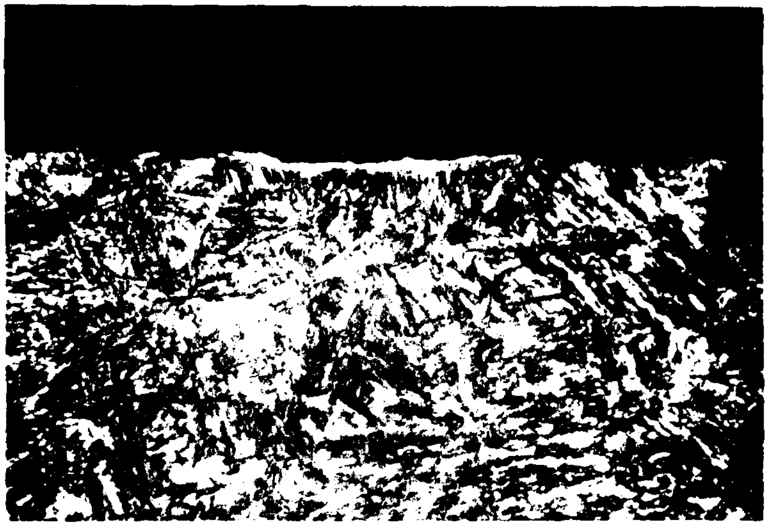
Generally Smooth Surface with Very Thin Light Etching Surface Layer (less than 0.0001 ins.). Isolated Instances of Surface Laps.

Mount No. 24175 1000X
HP 18-12 Max.

Generally Smooth Surface With Layer More Frequent Light Etching Scallops Than Low Stress Believed to be Untempered Martensite. Some Instances of Laps and Micro-cracks

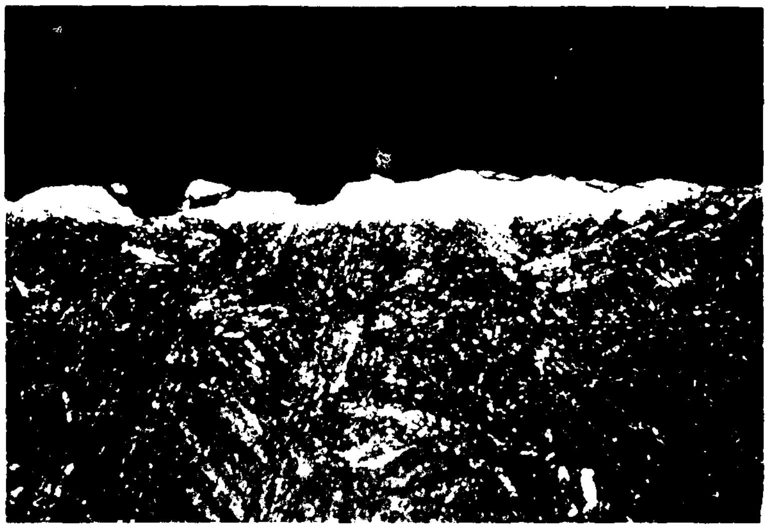
PHOTOMICROGRAPHS OF 4340 ESR STEEL SURFACE GROUND BY TECHNIQUES PERMITTED IN HP 18-12

Figure 2



Mount No. 24183 1000X
HP 15-51 Min.

Generally Smooth Surface with Isolated Instances of Scallops (UTM), Cracks and Laps

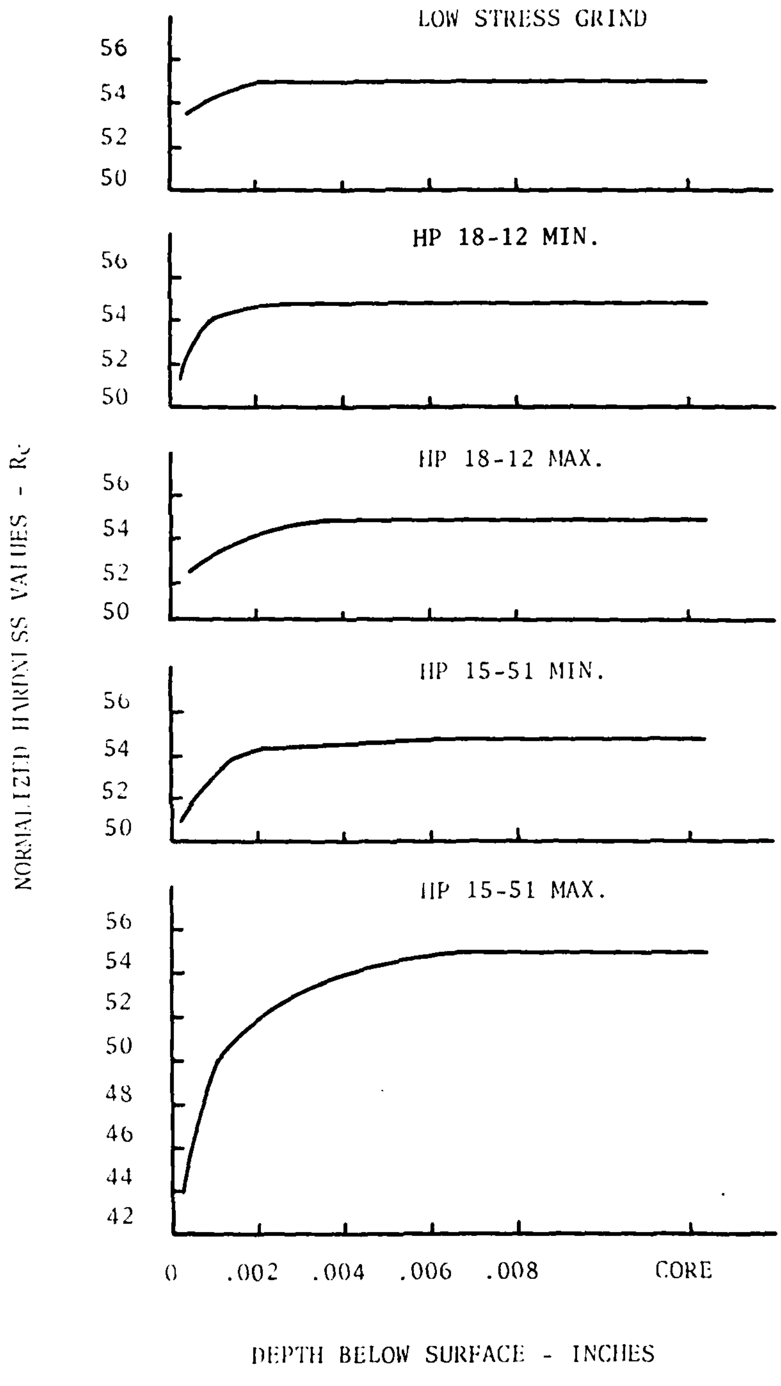


Mount No. 24181 1000X
HP 15-51 Max.

Larger and More Frequent Instances of Untempered Martensite, Laps and Cracks

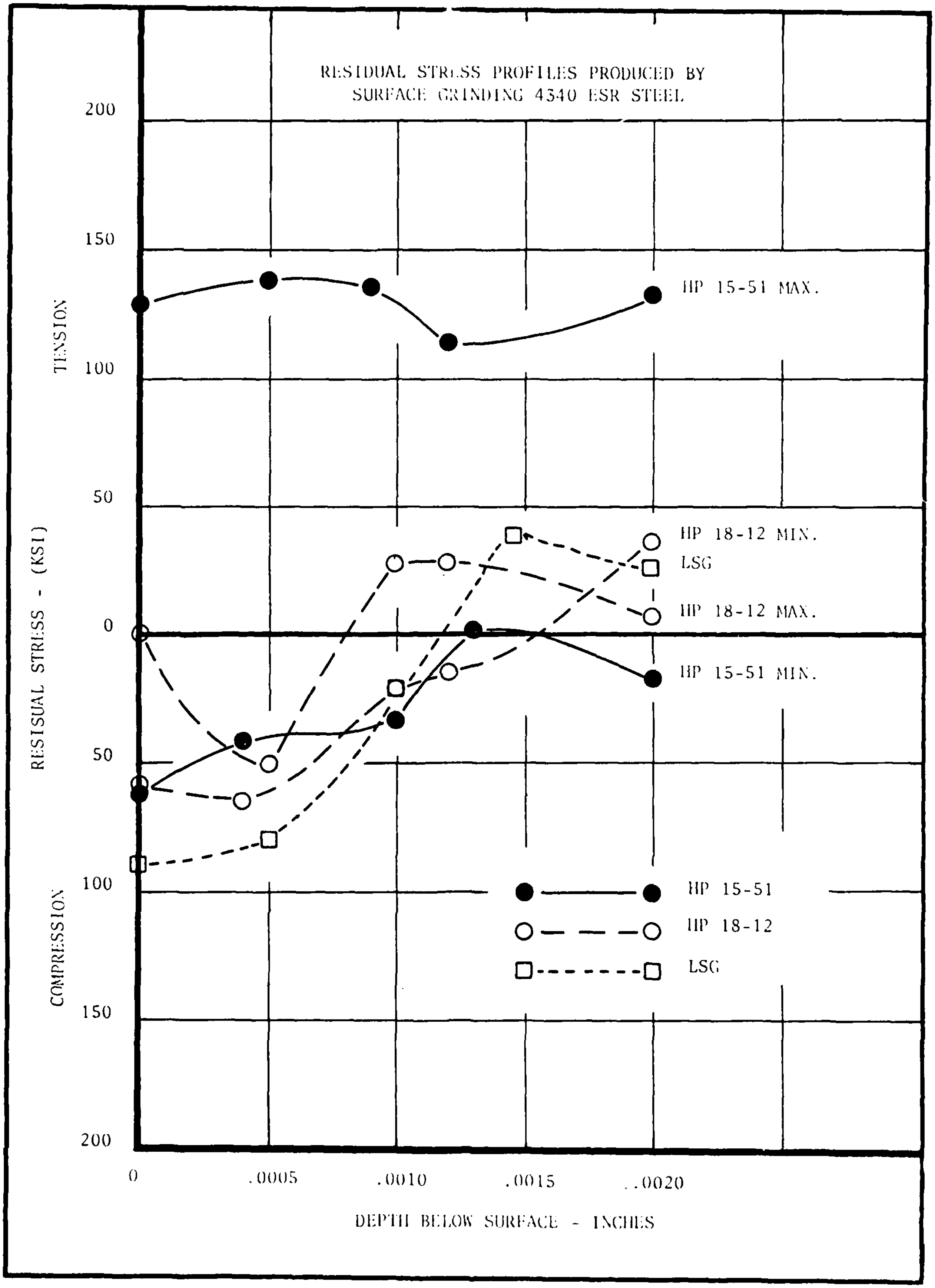
PHOTOMICROGRAPHS OF 4340 ESR STEEL SURFACE GROUND BY TECHNIQUES PERMITTED IN HP 15-51

Figure 3



MICROHARDNESS TRAVERSE PROFILES OF SURFACE GROUND 4340 ESR STEEL

Figure 4



RESIDUAL STRESS PROFILES PRODUCED BY
SURFACE GRINDING 4340 ESR STEEL
200
150
100
50
0
50
100
150
200
TENSION
COMPRESSION
RESISUAL STRESS - (KSI)
HP 15-51 MAX.
HP 18-12 MIN.
LSG
HP 18-12 MAX.
HP 15-51 MIN.
HP 15-51
HP 18-12
LSG
0
.0005
.0010
.0015
.0020
DEPTH BELOW SURFACE - INCHES

Figure 5

METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / Teletype 810-461-2840 / Telephone (513) 271-5100

Number: 1752-26887-2

Residual stress measurements were made using the technique recommended by the Society of Automotive Engineers. The specific technique employed differed from the more common SAE technique in two respects. First, the diffraction peak used for stress measurement was located using a five-point parabolic regression procedure rather than the three-point algebraic procedure more commonly used. Second, the intensities measured at each of the five points were corrected for the background intensity. These modifications improve the repeatability of stress measurements. Except for these modifications, the technique is identical to that described in the Society of Automotive Engineers Publication "Residual Stress Measurement by X-Ray Diffraction," SAW J784a. Details of the technique and diffractometer fixturing are outlined below:

Diffraction Peak: (211)
Radiation: CrKα
Incident Beam Divergence: 3°
Detection Slit: 0.7°
$E/(1 + \nu)$: 24.5×10^6 psi

The value of the elastic property $E/(1 + \nu)$ in the direction normal to the (211) crystallographic planes was taken to be the same as previously determined for hardened 4340 steel, 50 R_C. The determination of crystal elastic constants for the steel used to manufacture the ESR4340 Steel in question was not included in the scope of this program.

LABORATC RY REPORT

METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / Teletype 810-461-2840 / Telephone (513) 271-5100

Number: 1752-26887-2

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Diffraction Peak: (211)
Radiation: CrKα
Incident Beam Divergence: 3°
Detection Slit: 0.7°
$E/(1 + \nu)$: 24.5×10^6 psi

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Results

Surface residual stresses measured in each test surface were as follows:

Specimen	Depth Below Surface (in.)	Residual Stress * (ksi)
LSG	0.0000	-88.3
	0.0005	-79.8
	0.0010	-20.1
	0.0012	43.7
	0.0020	28.9
HP 18-12 MIN.	0.0000	-58.1
	0.0004	-64.2
	0.0010	-21.4
	0.0012	-14.5
	0.0020	31.7
HP 18-12 MAX.	0.0000	0.9
	0.0005	-50.7
	0.0010	27.8
	0.0012	29.3
	0.0020	8.5
HP 15-51 MIN.	0.0000	-61.5
	0.0004	-41.5
	0.0010	-33.0
	0.0013	4.5
	0.0020	-18.5
HP 15-51 MAX.	0.0000	127.8
	0.0005	138.0
	0.0009	136.4
	0.0012	114.5
	0.0020	133.0

* Negative value denotes compressive stress.

Details of the data analysis are shown in the attached computer printouts. The error shown for the stress values are ± one standard deviation resulting from random error in the calibration constant and uncertainty in the diffraction peak position. An additional systematic error of ± 3 ksi arises from instrument misalignment and sample positioning errors.

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

RESIDUAL STRESS DEPTH CORRECTION ANALYSIS

1752-26887 1-LSG   LONG., @ 2.0 MILS., GRN DIR.

E/(1+V)= 24500. +- 441. (KSI)   MU= 2196. (1/IN)

DATA POINT	DEPTH (IN.)	************ RESIDUAL STRESS (KSI ************ MEASURED	GRAD. CORRECTED	RELAX. CORRECTED
1	0.0000	-88.3 +- 2.4	-82.8	-82.8
2	0.0005	-79.8 +- 2.6	-93.4	-93.2
3	0.0010	-20.1 +- 1.7	-68.5	-68.1
4	0.0012	43.7 +- 1.6	-2.6	-2.2
5	0.0020	28.9 +- 1.6	0.0	0.1

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI OHIO

X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

1752-26887 1-LSG   LONG.,@ 2.0 MILS.,GRN DIR.

```
                          RESIDUAL STRESS (KSI)
  DEPTH  -100.0     -50.0      0.0      50.0     100.0     150.0     200.0
  (IN.)
             I----+----I----+----I----+----I----+----I----+----I----+----I
  0.0000     I  O
  0.0001     I  *
  0.0002     I *
  0.0004     I *
  0.0005     IO
  0.0006     I *
  0.0007     I   *
  0.0009     I    *
  0.0010     I     O
  0.0011     I             *
  0.0012     I                  O
  0.0014     I                     *
  0.0015     I                        *
  0.0016     I                          *
  0.0017     I                             *
  0.0019     I                               *
  0.0020     I                                  O
  0.0021     I
  0.0022     I
  0.0024     I
  0.0025     I
  0.0026     I
  0.0027     I
  0.0029     I
  0.0030     I
  0.0031     I
  0.0032     I
  0.0034     I
  0.0035     I
  0.0036     I
  0.0037     I
  0.0039     I
  0.0040     I
  0.0041     I
  0.0042     I
  0.0044     I
  0.0045     I
  0.0046     I
  0.0047     I
  0.0049     I
  0.0050     I
             I----+----I----+----I----+----I----+----I----+----I----+----I
              FITTED POINTS = *      MEASURED DATA = O
```

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 1-LSG LONG,SURFACE,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.000	33.040	308.448		
	154.500	32.220	275.249		
	155.000	31.740	258.709		
	155.700	32.220	277.681		
	156.200	33.030	313.329	1.17310	
					155.0736 +-0.0052
45.000	155.000	20.510	335.693		
	155.540	19.850	263.829		
	156.200	19.480	244.958		
	156.600	19.600	272.733		
	157.000	19.830	325.481	1.17099	
					156.0277 +-0.0031

E/(1+V) = 24500. +- 441. (KSI) STRESS = -88.3 +- 2.4 (KSI)

DELTA D = -0.00211 (A) STRAIN = -0.001802 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 1-LSG LONG.,@ 0.5 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.000	33.630	339.222		
	154.500	32.690	295.517		
	155.000	32.110	273.214		
	155.500	32.220	278.452		
	156.000	32.800	303.769	1.17285	
					155.1859 +-0.0053
45.000	155.000	23.700	137.001		
	155.500	23.090	126.990		
	156.200	22.600	121.162		
	156.600	22.820	127.663		
	157.000	23.010	134.060	1.17094	
					156.0506 +-0.0075

E/(1+V) = 24500. +- 441. (KSI) STRESS = -79.8 +- 2.6 (KSI)

DELTA D = -0.00191 (A) STRAIN = -0.001629 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-24887 1-LSG-1 LONG,SURFACE,REPOSITIONED,GRN DIR

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.000	33.490	323.715		
	154.500	32.479	280.234		
	155.000	31.960	262.298		
	155.500	32.220	272.697		
	156.000	32.770	295.659	1.17296	
					155.1322 +-0.0052
45.000	155.000	23.220	205.513		
	155.500	22.290	171.071		
	156.200	21.780	158.636		
	156.600	21.930	166.343		
	157.000	22.180	183.566	1.17076	
					156.1342 +-0.0043

E/(1+V) = 24500. +- 441. (KSI) STRESS = -91.9 +- 2.5 (KSI)

DELTA D = -0.00220 (A) STRAIN = -0.001875 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 1-LSG LONG.,@ 1.0 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	34.190	335.737		
	155.000	33.410	300.845		
	155.500	33.080	288.385		
	156.000	33.390	302.240		
	156.500	33.810	322.295	1.17200	
					155.5655 +-0.0064
45.000	155.000	23.680	190.233		
	155.500	23.310	180.911		
	156.000	23.100	178.342		
	156.500	23.220	189.370		
	157.000	23.440	206.631	1.17152	
					155.7837 +-0.0078

E/(1+V) = 24500. +- 441. (KSI) STRESS = -20.1 +- 1.7 (KSI)

DELTA D = -0.00049 (A) STRAIN = -0.000410 (IN./IN.

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 1-LSG LONG.,@ 1.2 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	42.670	856.428		
	155.500	42.400	807.631		
	156.000	42.120	770.548		
	156.500	42.470	831.251		
	157.000	42.770	901.068	1.17131	
					155.8821 +-0.0064
45.000	154.500	29.180	545.353		
	155.000	29.020	546.182		
	155.500	28.470	466.190		
	156.000	28.630	531.248		
	156.700	28.740	620.532	1.17235	
					155.4088 +-0.0047

E/(1+V) = 24500. +- 441. (KSI) STRESS = 43.7 +- 1.6 (KSI)

DELTA D = 0.00104 (A) STRAIN = 0.000892 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 1-LSG   LONG.,@ 2.0 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	43.750	1031.169		
	155.500	43.370	936.834		
	156.000	43.170	896.035		
	156.500	43.490	980.265		
	157.000	43.770	1067.564	1.17123	
					155.9167 +-0.0054
45.000	155.000	30.470	333.588		
	155.500	30.300	332.759		
	156.200	30.020	328.188		
	156.600	30.370	370.049		
	157.000	30.660	415.211	1.17192	
					155.6022 +-0.0064

E/(1+V) = 24500. +- 441. (KSI)   STRESS = 28.9 +- 1.6 (KSI)

DELTA D = 0.00067 (A)   STRAIN = 0.000590 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

RESIDUAL STRESS DEPTH CORRECTION ANALYSIS

1752-268*7 3-18-12-MIN LONG.,@ 2.0 MILS.,GRN DIR.

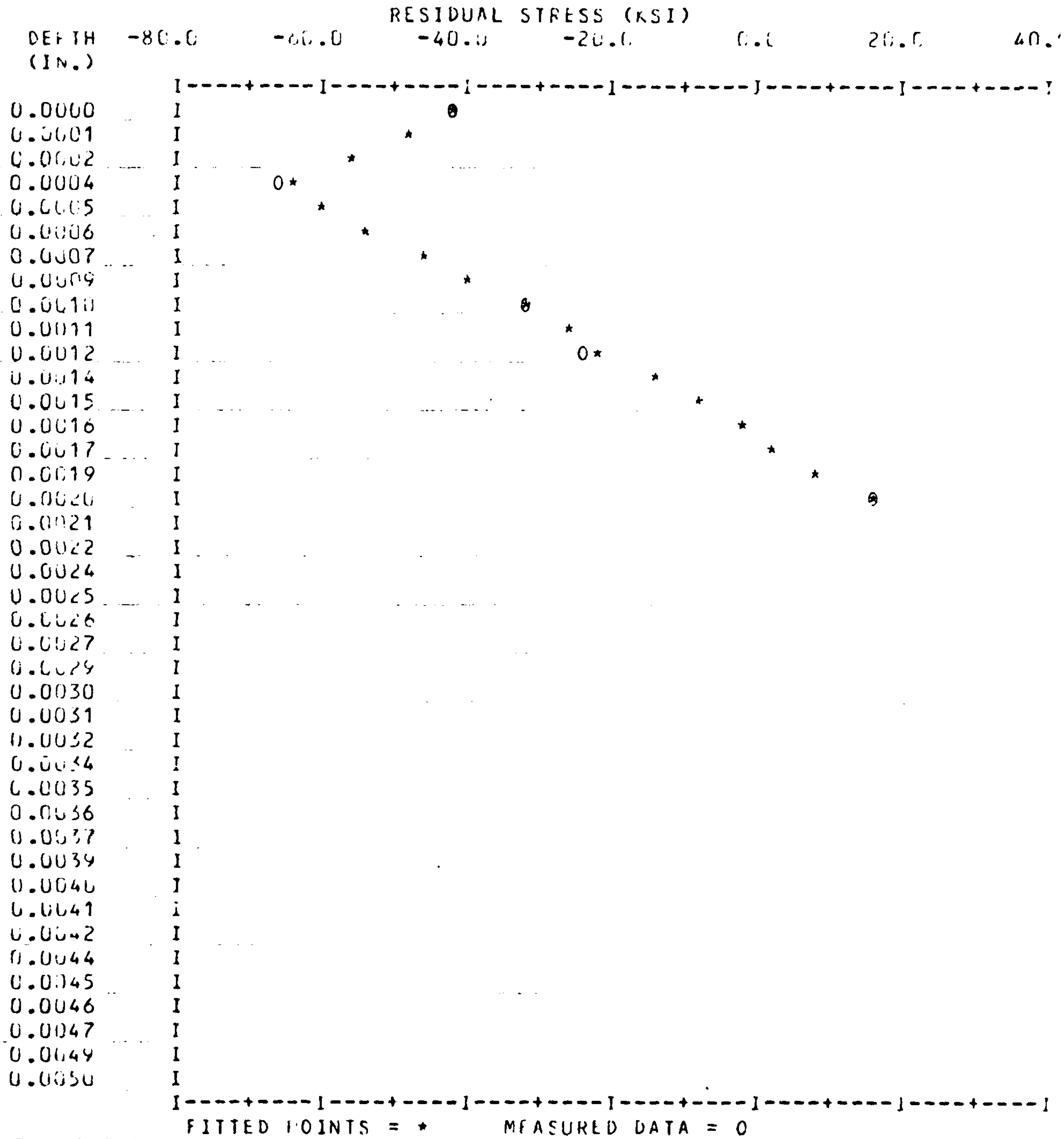
E/(1+V)= 24500. +- 441. (KSI) MU= 2196. (1/IN)

DATA POINT	DEPTH (IN.)	************ MEASURED	RESIDUAL STRESS (KSI GRAD. CORRECTED	************ RELAX. CORRECTED
1	0.0000	-58.1 +- 2.5	-41.8	-41.[illegible]
2	0.0004	-64.2 +- 1.6	-66.2	-66.1
3	0.0010	-21.4 +- 1.5	-31.[illegible]	-31.[illegible]
4	0.0012	-14.5 +- 1.5	-23.4	-23.[illegible]
5	0.0020	31.7 +- 1.6	17.0	17.[illegible]

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI OHIO

X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

1752-26887 3-18-12-MIN LONG.,@ 2.0 MILS.,GRN DIR.



METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 3-18-12-MIN LONG.SURFACE,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	33.250	313.035		
	154.700	33.800	340.875		
	155.000	32.590	285.555		
	155.500	32.930	300.778		
	156.000	33.260	316.833	1.17253	
					155.3268 +-[illegible].064
45.000	155.000	23.070	109.128		
	155.500	22.390	101.418		
	156.000	22.150	100.061		
	156.700	22.360	105.777		
	157.000	22.570	110.227	1.17114	
					155.9571 +-[illegible]

E/(1+V) = 24500. +- 441. (KSI) STRESS = -58.1 +- 2.5 (KSI)

DELTA D = -0.00139 (A) STRAIN = -0.001186 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 3-18-12-MIN LONG.,@ 0.4 MILS,GRN DIR

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.000	41.010	751.168		
	154.500	40.470	669.028		
	155.000	39.860	593.391		
	155.500	40.170	634.341		
	156.000	40.890	746.036	1.17320	
					155.0312 +-[illegible]
45.000	155.000	27.620	1408.052		
	155.500	27.170	1055.646		
	156.000	26.940	1010.428		
	156.500	27.000	1301.208		
	157.000	27.340	3314.546	1.17166	
					155.7197 +-[illegible]14

[illegible] = 24500. +- 441. (KSI) STRESS = -64.2 +- 1.6 (KSI)

[illegible] = -[illegible]154 (A) STRAIN = -0.001310 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 3-18-12-MIN LONG.,@ 1.0 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	33.920	325.095		
	155.000	33.350	306.406		
	155.500	33.010	287.447		
	156.000	33.340	302.015		
	156.600	34.030	335.422	1.17219	
					155.4819 +-0.0064
45.000	155.000	23.330	170.294		
	155.500	22.890	160.539		
	155.900	22.710	158.686		
	156.500	22.920	172.404		
	157.000	23.450	201.488	1.17168	
					155.7137 +-0.0054

E/(1+V) = 24500. +- 441. (KSI) STRESS = -21.4 +- 1.5 (KSI)

DELTA D = -0.00051 (A) STRAIN = -0.00043? (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 3-18-12-MIN LONG.,@ 1.2 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	34.170	339.171		
	155.000	33.810	322.506		
	155.800	33.390	305.110		
	156.300	33.770	323.532		
	156.800	34.330	353.482	1.17199	
					155.5708 +-0.0076
45.000	155.000	23.750	196.653		
	155.500	23.340	185.596		
	156.000	23.100	182.171		
	156.500	23.340	199.920		
	157.000	23.710	228.623	1.17164	
					155.7280 +-0.0055

E/(1+V) = 24500. +- 441. (KSI) STRESS = -14.5 +- 1.5 (KSI)

DELTA D = -0.00035 (A) STRAIN = -0.000296 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26867 3-18-12-MIN LONG., @ 2.0 MILS., GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	44.270	924.298		
	155.500	43.730	818.613		
	156.000	43.570	794.200		
	156.700	44.100	903.470		
	157.300	44.520	1011.533	1.17116	
					155.9479 +-0.0051
45.000	155.300	29.740	584.684		
	155.700	29.540	570.317		
	156.300	29.470	608.557		
	156.800	29.610	713.033		
	157.300	29.680	822.211	1.17192	
					155.6026 +-0.0059

E/(1+V) = 24500. +- 441. (KSI) STRESS = 31.7 +- 1.6 (KSI)

DELTA D = 0.00076 (A) STRAIN = 0.000647 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

RESIDUAL STRESS DEPTH CORRECTION ANALYSIS

1752-26887 2-18-12-MAX LONG., @ 2.0 MILS., GRN DIR.

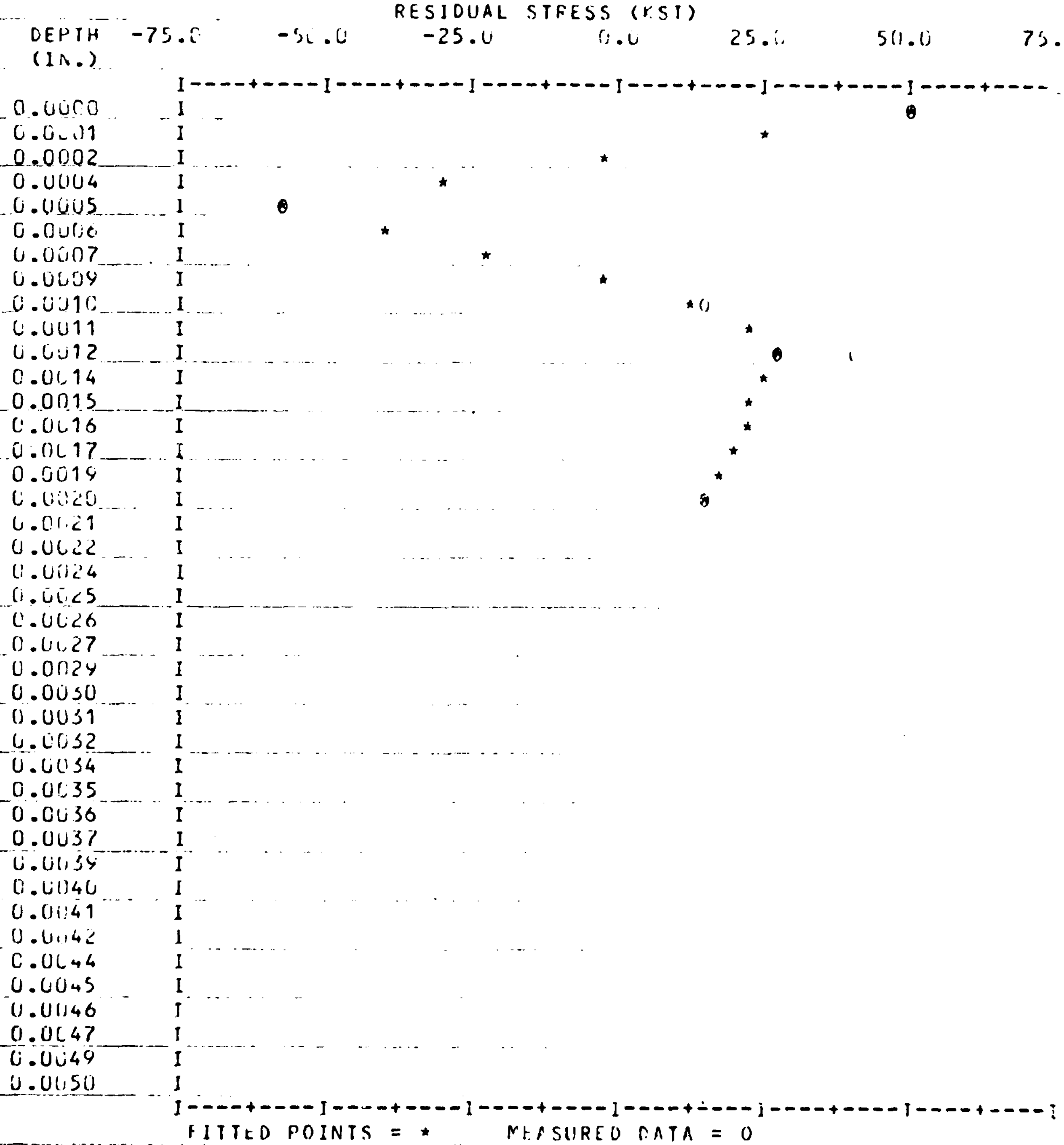
E/(1+V)= 24500. +- 441. (KSI) MU= 2196. (1/IN)

DATA POINT	DEPTH (IN.)	************ MEASURED	RESIDUAL STRESS (KSI GRAD. CORRECTED	************ RELAX. CORRECTED
1	0.0000	0.9 +- 0.5	52.6	52.6
2	0.0005	-50.7 +- 1.1	-58.6	-58.6
3	0.0010	27.8 +- 1.6	17.5	17.6
4	0.0012	29.3 +- 1.8	30.5	30.5
5	0.0020	8.5 +- 0.3	17.8	17.7

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI OHIO

X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

1752-26887 2-16-12-MAX LONG., 2.0 MILS., GRN DIP.



METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 2-18-12-MAX   LONG,SURFACE,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	32.570	291.325		
	155.000	31.820	263.193		
	155.500	31.500	252.912		
	156.000	31.700	260.620		
	156.400	32.480	291.317	1.17222	
					155.4675 +-0.0057
45.000	154.500	23.340	306.998		
	155.000	22.620	252.316		
	155.500	22.210	233.076		
	156.000	22.310	254.074		
	156.400	22.700	307.378	1.17224	
					155.4576 +-0.0031

E/(1+V) = 24500. +- 441. (KSI)   STRESS = 0.9 +- 0.[illegible] (KSI)

DELTA D = 0.00002 (A)   STRAIN = 0.00001[illegible] (IN./IN.

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 2-18-12-MAX   LONG.,@ 0.5 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	33.610	299.900		
	155.000	32.500	259.407		
	155.600	31.790	238.132		
	156.300	31.910	242.704		
	156.600	0.030	0.058	1.17333	
					154.9737 +--.0014
45.000	154.500	23.430	265.417		
	155.000	22.590	216.042		
	155.700	22.140	202.891		
	156.400	22.520	242.511		
	156.700	23.010	296.182	1.17212	
					155.5144 +-0.0031

E/(1+V) = 24500. +- 441. (KSI)   STRESS = -50.7 +- 1.1 (KSI)

DELTA D = -0.00121 (A)   STRAIN = -0.001035 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26867 2-18-12-MAX-1 LONG,SURFACE,REPOSITIONED,GRN DIR

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	33.210	293.558		
	155.000	32.420	264.624		
	155.500	32.150	256.263		
	156.000	32.630	273.863		
	156.500	33.470	308.700	1.17235	
					155.4099 +-0.0057
45.000	154.500	23.550	253.624		
	155.000	22.730	209.642		
	155.700	22.420	204.871		
	156.100	22.500	217.075		
	156.500	22.950	258.708	1.17219	
					155.4741 +-0.0039

E/(1+V) = 24500. +- 441. (KSI) STRESS = -6.4 +- 1.0 (KSI)

DELTA D = -0.00015 (A) STRAIN = -0.000131 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 2-16-12-MAX LONG.,@ 1.0 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	33.570	301.842		
	155.500	33.070	282.716		
	156.000	32.800	273.561		
	156.500	32.990	281.490		
	157.000	33.500	302.903	1.17106	
					155.9978 +-0.0084
45.000	155.000	23.430	300.795		
	155.500	22.970	271.156		
	156.000	22.820	272.721		
	156.500	23.020	312.024		
	157.000	23.430	400.073	1.17172	
					155.6752 +-0.036

E/(1+V) = 24500. +- 441. (KSI) STRESS = 27.6 +- 1.6 (KSI)

DELTA D = 0.00066 (A) STRAIN = 0.000567 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 2-18-12-MAX LONG.,@ 1.2 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	42.570	808.861		
	155.500	42.220	751.045		
	156.000	41.940	710.599		
	156.700	42.350	782.657		
	157.300	42.880	894.175	1.17114	
					155.9580 +-0.055
45.000	155.000	29.000	208.799		
	155.500	28.660	209.673		
	156.000	28.440	200.929		
	156.500	28.740	217.261		
	157.300	29.100	242.966	1.17184	
					155.6368 +-0.0082

E/(1+V) = 24500. +- 441. (KSI) STRESS = 29.3 +- 1.8 (KSI)

DELTA D = 0.00070 (A) STRAIN = 0.000597 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26687 2-18-12-MAX LONG., @ 2.0 MILS., GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	155.000	44.190	965.783		
	155.500	43.720	880.658		
	156.000	43.570	854.400		
	156.500	43.870	923.765		
	157.000	44.880	1234.810	1.17150	
					155.7959 +- .0034
45.000	155.000	33.370	-2422.256		
	155.500	33.070	-2877.042		
	156.000	32.880	-2865.226		
	156.700	32.920	-1659.002		
	157.000	33.030	-1483.159	1.17170	
					155.7038 +- .[illegible]

E/(1+V) = 24500. +- 441. (KSI) STRESS = 8.5 +- 0.[illegible] (KSI)

DELTA D = 0.00020 (A) STRAIN = 0.000173 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

RESIDUAL STRESS DEPTH CORRECTION ANALYSIS

1752-26887 5-15-51-MIN LONG.,@ 2.0 MILS.,GRN DIR.

E/(1+V)= 24500. +- 441. (KSI) MU= 2196. (1/IN)

DATA POINT	DEPTH (IN.)	************ MEASURED	RESIDUAL STRESS (KSI GRAD. CORRECTED	************ RELAX. CORRECTED
1	0.0000	-61.5 +- 1.8	-72.0	-72.0
2	0.0004	-41.5 +- 1.5	-48.1	-48.0
3	0.0010	-33.0 +- 1.4	-51.2	-51.0
4	0.0013	4.5 +- 1.0	-11.3	-11.[illegible]
5	0.0020	-18.5 +- 0.9	10.0	10.2

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI OHIO

X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG.,@ 2.0 MILS.,GRN DIR.

```
                              RESIDUAL STRESS (KSI)
 DEPTH  -80.0     -60.0     -40.0     -20.0       0.0      20.0      40.0
 (IN.)
            I----+----I----+----I----+----I----+----I----+----I----+----I
  0.0000    I   @
  0.0001    I      *
  0.0002    I          *
  0.0004    I              *0
  0.0005    I               *
  0.0006    I              *
  0.0007    I              *
  0.0009    I              *
  0.0010    I             @
  0.0011    I                     *
  0.0012    I                             *   0
  0.0014    I                                  *
  0.0015    I                                    *
  0.0016    I                                      *
  0.0017    I                                       *
  0.0019    I                                         *
  0.0020    I                                           @
  0.0021    I
  0.0022    I
  0.0024    I
  0.0025    I
  0.0026    I
  0.0027    I
  0.0029    I
  0.0030    I
  0.0031    I
  0.0032    I
  0.0034    I
  0.0035    I
  0.0036    I
  0.0037    I
  0.0039    I
  0.0040    I
  0.0041    I
  0.0042    I
  0.0044    I
  0.0045    I
  0.0046    I
  0.0047    I
  0.0049    I
  0.0050    I
            I----+----I----+----I----+----I----+----I----+----I----+----I
             FITTED POINTS = *       MEASURED DATA = 0
```

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG,SURFACE,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.200	33.830	324.907		
	154.700	32.760	279.958		
	155.300	32.430	268.853		
	155.800	32.760	282.096		
	156.200	33.570	317.326	1.17274	
					155.2340 +-0.0049
45.000	155.000	23.370	381.148		
	155.500	22.790	320.362		
	156.000	22.370	291.299		
	156.700	22.500	341.271		
	157.000	22.980	458.229	1.17127	
					155.8986 +-0.0026

E/(1+V) = 2450[illegible]. +- 441. (KSI) STRESS = -61.5 +- 1.8 (KSI)

DELTA D = -0.00147 (A) STRAIN = -0.001255 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG.,@ 0.4 MILS.,FRM DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST. DEV.
0.000	154.000	41.320	779.048		
	154.500	40.760	689.449		
	155.000	40.230	620.412		
	155.500	40.300	632.392		
	156.000	40.540	668.089	1.17261	
					155.2944 +-0.0055
45.000	155.000	27.780	1009.900		
	155.500	27.420	882.245		
	156.000	27.110	809.418		
	156.500	27.160	985.448		
	157.000	27.400	1590.387	1.17161	
					155.7419 +-0.0071

E/(1+V) = 24500. +- 441. (KSI) STRESS = -41.5 +- 1.5 (KSI)

DELTA D = -0.00099 (A) STRAIN = -0.000847 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG., @ 1.0 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.000	35.470	415.147		
	154.500	33.870	322.941		
	155.000	33.210	294.806		
	155.500	32.780	278.828		
	156.000	33.190	296.059	1.17231	
					155.4277 +-0.0046
45.000	155.000	23.640	329.376		
	155.500	23.060	283.626		
	156.000	22.940	289.796		
	156.500	23.020	320.005		
	157.000	23.290	388.944	1.17152	
					155.7852 +-0.0041

E/(1+V) = 24500. +- 441. (KSI) STRESS = -33.0 +- 1.4 (KSI)

DELTA D = -0.00079 (A) STRAIN = -0.000674 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG.,@ 1.3 MILS.,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	42.010	791.733		
	155.000	41.550	717.504		
	155.500	41.080	653.533		
	156.000	41.280	684.453		
	156.500	41.450	713.348	1.17166	
					155.7206 +-0.0060
45.000	155.000	28.450	724.354		
	155.500	25.210	236.221		
	156.000	27.870	648.483		
	156.500	27.960	768.304		
	157.000	28.050	940.744	1.17177	
					155.6717 +-0.0036

E/(1+V) = 24500. +- 441. (KSI) STRESS = 4.5 +- 1.0 (KSI)

DELTA D = 0.00011 (A) STRAIN = 0.000092 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 5-15-51-MIN LONG., @ 2.0 MILS., GRN DIP.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	154.500	44.120	943.508		
	155.000	43.840	885.667		
	155.500	43.520	826.386		
	156.000	43.750	876.914		
	156.500	43.910	917.072	1.17199	
					155.5705 +-0.0071
45.000	155.000	29.960	-2652.369		
	155.500	29.480	-5862.312		
	155.950	29.320	-5240.021		
	156.500	29.520	-1929.152		
	157.000	29.660	-1280.087	1.17155	
					155.7716 +--.0005

E/(1+V) = 24500. +- 441. (KSI)   STRESS = -18.5 +- 0.9 (KSI)

DELTA D = -0.00044 (A)   STRAIN = -0.000378 (IN./IN.)

AD-A088 451 HUGHES HELICOPTERS CULVER CITY CALIF F/G 13/8
CONVENTIONAL MACHINING OF ESR 4340 STEEL.(U)
JUL 80 K K NIJI DAAG46-78-C-0046
UNCLASSIFIED HH-80-125 USAAVRADCOM-TR-80-F-14 NL

2 OF 2
AD
A088451

END
DATE
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METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

RESIDUAL STRESS DEPTH CORRECTION ANALYSIS

1752-26887 4-15-51-MAX   LONG.,@ 2.0 MILS.,GRN DIR.

E/(1+V)=   24500. +- 441. (KSI)   MU= 2196. (1/IN)

DATA POINT	DEPTH (IN.)	************ MEASURED	RESIDUAL STRESS (KSI GRAD. CORRECTED	************ RELAX. CORRECTED
1	0.0000	127.8 +- 3.0	119.4	119.4
2	0.0005	138.0 +- 3.1	136.8	136.5
3	0.0009	136.4 +- 3.0	143.5	143.1
4	0.0012	114.5 +- 2.7	122.0	121.3
5	0.0020	133.0 +- 2.7	120.6	119.6

```
                        METCUT RESEARCH ASSOCIATES INC.
                                CINCINNATI OHIO

                 X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

            1752-26887 4-15-51-MAX     LONG.,@ 2.0 MILS.,GRN DIR.

                                  RESIDUAL STRESS (KSI)
    DEPTH   115.0     120.0     125.0     130.0     135.0     140.0     145.0
    (IN.)
              I----+----I----+----I----+----I----+----I----+----I----+----I
    0.0000    I      0
    0.0001    I              *
    0.0002    I                       *
    0.0004    I                               *
    0.0005    I                                        *0
    0.0006    I                                            *
    0.0007    I                                                *
    0.0009    I                                                    * 0
    0.0010    I                                         *
    0.0011    I                       *
    0.0012    I          0
    0.0014    I         *
    0.0015    I         *
    0.0016    I        *
    0.0017    I        *
    0.0019    I       *
    0.0020    I       0
    0.0021    I
    0.0022    I
    0.0024    I
    0.0025    I
    0.0026    I
    0.0027    I
    0.0029    I
    0.0030    I
    0.0031    I
    0.0032    I
    0.0034    I
    0.0035    I
    0.0036    I
    0.0037    I
    0.0039    I
    0.0040    I
    0.0041    I
    0.0042    I
    0.0044    I
    0.0045    I
    0.0046    I
    0.0047    I
    0.0049    I
    0.0050    I
              I----+----I----+----I----+----I----+----I----+----I----+----I
                FITTED POINTS = *       MEASURED DATA = 0
```

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 4-15-51-MAX LONG,SURFACE,BURNED AREA,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	156.300	32.420	291.593		
	156.600	31.340	251.874		
	157.300	31.140	246.075		
	157.700	31.620	263.112		
	158.000	32.050	279.848	1.16852	
					157.1951 +-0.0048
45.000	155.000	21.750	229.704		
	155.500	21.120	199.203		
	156.000	20.900	196.275		
	156.500	21.160	224.667		
	157.000	21.760	298.835	1.17157	
					155.7619 +-0.0031

E/(1+V) = 24500. +- 441. (KSI) STRESS = 127.8 +- 3.0 (KSI)

DELTA D = 0.00305 (A) STRAIN = 0.002607 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 4-15-51-MAX LONG.,& 0.5 MILS,GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	156.500	29.790	207.165		
	156.900	28.890	186.590		
	157.300	28.540	179.607		
	157.700	28.660	182.503		
	158.100	29.600	204.358	1.16825	
					157.3287 +-0.0050
45.000	155.000	21.230	184.444		
	155.500	20.270	150.180		
	156.000	20.030	147.322		
	156.500	20.500	173.290		
	157.000	21.620	258.872	1.17154	
					155.7759 +-0.0024

E/(1+V) = 24500. +- 441. (KSI) STRESS = 138.0 +- 3.1 (KSI)

DELTA D = 0.00329 (A) STRAIN = 0.002816 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 4-15-51-MAX LONG., @ 0.9 MILS., GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	156.000	32.540	271.962		
	156.500	30.770	218.096		
	157.000	29.570	190.220		
	157.500	29.650	192.468		
	158.000	30.600	215.597	1.16838	
					157.2630 +-0.0036
45.000	155.000	22.720	189.044		
	155.500	22.020	166.584		
	156.000	21.870	167.154		
	156.500	22.110	184.209		
	157.000	23.270	267.895	1.17164	
					155.7318 +-0.0029

E/(1+V) = 24500. +- 441. (KSI) STRESS = 136.4 +- 3.0 (KSI)

DELTA D = 0.00325 (A) STRAIN = 0.002784 (IN./IN.)

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 4-15-51-MAX LONG., @ 1.2 MILS., GRN DIR.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	156.300	31.350	227.624		
	156.700	30.370	203.328		
	157.300	29.850	192.335		
	157.600	30.320	203.200		
	157.900	30.460	206.650	1.16841	
					157.2511 +-0.0055
45.000	155.000	22.020	186.349		
	155.500	23.320	290.463		
	156.000	20.000	126.003		
	156.500	21.300	176.223		
	157.000	22.380	252.775	1.17114	
					155.9592 +-0.0019

E/(1+V) = 24500. +- 441. (KSI) STRESS = 114.5 +- 2.7 (KSI)

DELTA D = 0.00273 (A) STRAIN = 0.002337 (IN./IN.)

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI, OHIO

FIVE POINT PARABOLIC DIFFRACTION PEAK STRESS ANALYSIS

1752-26887 4-15-51-MAX LONG.,@ 2.0 MILS.,GEN DIP.

PSI	2 THETA	TIME	COR. TIME	D (A)	VERTEX +- ST.DEV.
0.000	156.000	43.910	1004.309		
	156.500	43.030	811.831		
	157.300	42.220	688.466		
	157.600	42.530	736.001		
	158.000	43.390	899.518	1.16767	
					157.1221 +-0.0029
45.000	155.000	29.360	1543.133		
	155.500	28.930	1205.224		
	156.000	28.820	1318.065		
	156.500	28.970	2675.323		
	157.000	29.250	9213.071	1.17185	
					155.6362 +-0.0010

E/(1+V) = 24500. +- 441. (KSI) STRESS = 133.0 +- 2.7 (KSI)

DELTA D = 0.00317 (A) STRAIN = 0.002715 (IN./IN.)

APPENDIX E

HP 18-12, Hughes Helicopters specification for low stress grinding of high strength steel. This specification was released during the course of this program It is included here as it was originally written. Based on the efforts of this program, some changes are recommended as discussed in the content of the report.

Hughes Helicopters
division of su... corporation

ENGINEERING O' ER

E.O. NO. 32596

MODEL	EFFECTIVE ON	E.O. TYPE	AUTHORITY
All	Record	Process Specification	MJO 0136
		PARTS MAY BE REWORKED: / RECORD: X	
		PARTS MADE OK TO USE: / NOTED:	CCN/MOD

AFF.GROUP	SPECIFICATION AFFECTED	ATP FTP AFFECTED	INTERCHANGEABILITY AFFECTED	E.O. BY
	NO. YES ☐ NO ☒	NO. YES ☐ NO ☒	YES ☐ NO ☒	L. Soffa

DOCUMENT	REV.	SIGNIFICANT CHANGE YES ☐ NO ☐	GROUP	DATE
HP 18-12	New	Low Stress Grinding of High Strength Steel (ESR 4340, 300M VAR 4340) at Strength Levels of 260 to 300 ksi	18-10	8-23-79
			NEXT ASSY.	

REL.DATE	BY:
9-7-79	C. J. Cramf

DRAWING TO BE CHANGED: YES ☐ NO ☒

APPROVED BY	DATE
PE 77 Chandler	8/22/79
PE 302A O. Mont	8 22 79
STRESS [illegible]	8-23-79
PE COMM'L R.F. Salahi	8/21/79
TECH. DEPT. R.Bauer	8/23/79
MAT'L & PROCESS J.C. French	8-21-7
CHANGE CONT.	
CONF. CONT. [illegible]	8-28-9
SPRT SERVICES	
SYSTEMS [illegible]	8/24/79
PA [illegible]	8/22/79
MFG [illegible]	8-22-79
COPIES TO	
ORDNANCE R.V. [illegible]	8/22/79

SAXLUND 8

REFERENCED E.O.'S

REASONS & REMARKS
To provide new processing specification

E.O. NO. 132596

FORM 9022 REV. 2/74

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
New	Released on EO 132596	08/23/79	

SCOPE: This process specification establishes the requirements and procedures for grinding hardened steel and chrome-plated steel parts by surface, cylindrical, and centerless grinding methods using bonded abrasive wheels. This process is specifically intended for grinding of ESR 4340, 300M, and VAR 4340 steels at strength levels of 260 to 300 ksi.

PREP	[signature]
APPD	[signature]
8/21/79	R. J. Salati
8/22/79	[signature]
8/22/79	[signature]
8-22-79	[signature]
8/22/79	[signature]
8/23/79	[signature]
8/23/79	[signature]
8/23/78	[signature]

FORM 1642

Hughes Helicopters
Division of Summa Corporation
Centinela and Teale Streets
Culver City, California 90230

TITLE LOW STRESS GRINDING OF HIGH STRENGTH STEEL (ESR 4340, 300M AND VAR 4340) AT STRENGTH LEVELS OF 260 TO 300 KSI

SIZE	CODE IDENT NO.	NO.	REV.
A	02731	HP 18-12	New

SHEET 1 of 10

1. SCOPE

1.1 This process specification establishes the requirements and procedures for grinding hardened steel and chrome-plated steel parts by surface, cylindrical, and centerless grinding methods using bonded abrasive wheels. This process is specifically intended for grinding of ESR 4340, 300M, and VAR 4340 steels at strength levels of 260 to 300 ksi.

1.2 Classification. The steels covered by the requirements of this specification are listed by AISI and HH designations and by heat-treat ranges.

AISI Designation	HH Designation	Heat Treat Range
4340		260 to 280 ksi (1793 to 1931 MPa)
300M		280 to 300 ksi (1931 to 2069 MPa)
	4340 ESR	R_c 54 (280 ksi, min) (1931 MPa)

2. APPLICABLE DOCUMENTS

2.1 Government documents. The following documents, of the issue in effect on date of the invitation for bids or request for proposal, form a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, the requirements of this specification shall prevail.

SPECIFICATIONS

Military

MIL-H-6875	Heat Treatment of Steels (Aerospace Practice, Process for
MIL-S-8844	Steel Bars, Reforging Stock and Mechanical Tubing, Low Alloy, Premium Quality

2.1.1 Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

2.2 Non-Government documents. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply. In case of conflict between these documents and this specification, the requirements of this specification shall prevail.

SPECIFICATIONS

Industry

Hughes Helicopters

HP 1-1	Heat Treatment of Steels Nickel Base and Cobalt-Base Alloys
HP 1-9	Hydrogen Embrittlement Relief
HP 4-1	Corrosion and Handling Protection
HP 6-5	Magnetic Particle Inspection
HP 6-19	Hardness Testing of Metals
HP 9-25	Vapor Degreasing
HP 30-4	Etching for Detection of Grinding Burns
HMS 6-1121	4340 ESR Steel

OTHER PUBLICATIONS

American Society for Metals

Metals Handbook (8th Edition - Volume 3)	Machining

Machining Data Center

MDC 78-103 — Low Stress Grinding for Quality Production

3. REQUIREMENTS

3.1 Equipment

3.1.1 Machines. Grinding machines used shall be equipped with:

a. Positive controls to maintain feed and speed limitations during processing.

b. A system providing continuous filtered coolant flow at the part/grinding wheel interface.

c. Tooling capable of holding parts in a completely rigid position during processing.

3.1.2 Grinding wheels. Wheels used shall be vitrified-bonded, aluminum oxide, or equivalent, as described in the ASM Handbook on machining and in MDC 78-103, and shall have an appropriate grit size to produce the desired finish.

3.2 Procedures

3.2.1 Cleaning. Parts shall be cleaned in accordance with the requirements of HP 9-25 (do not anodic clean) prior to grinding.

3.2.2 Dressing. Grinding wheels shall be dressed, as necessary, but always prior to rough and finish grinding.

3.2.3 Grinding. All grinding shall be performed on the periphery surface of the grinding wheel only. Grinding on the flat side of the wheel shall be forbidden.

3.2.4 Coolant. Coolant shall be supplied continuously across the width of the grinding wheel and directly into the part/wheel interface. The direction of coolant flow shall coincide with wheel rotation.

3.2.5 High spots. Prior to starting the grinding operation, high spots on the part shall be located to avoid accidental excessive infeed during grinding.

3.3 Grinding requirements

3.3.1 Surface and cylindrical grinding. All surface and cylindrical grinding shall be accomplished in accordance with 3.3.1.1 and 3.3.1.2 herein.

3.3.1.1 Limitations. Surface and cylindrical grinding limitations shall be as specified in Table I.

3.3.1.2 Technique data cards. Surface and cylindrical grinding shall meet the requirements of a technique data card established for each part and shall be maintained at the vendor facility for HH review.

3.3.1.2.1 The technique specified on the data card shall have been demonstrated to produce ground surfaces in conformance to the requirements of the engineering drawing.

3.3.1.2.2 A record of all changes in technique data cards showing effectivity (date or serial number) shall be maintained. The technique data card shall include the following information and other pertinent data as required:

a. Part number.

b. Outline of surfaces to be ground.

c. Grinding machines authorized for use.

d. Required tooling.

e. Wheel speed.

f. Workpiece (part) speed.

g. Infeed rates.

h. Cross feed.

i. Wheel dressing practice, including number of passes between redressing for both rough and finish grinding.

j. Coolant-type, supply rate, and nozzle location.

NOTE

Tolerances shall be noted for feeds and speeds.

TABLE I. SURFACE AND CYLINDRICAL GRINDING LIMITATIONS FOR HARDENED STEEL AND CHROME PLATE ON HARDENED STEEL

Parameter	Chrome Plate	ESR 4340 and 300M		4340 at 260-280 ksi	
Wheel Grade	I or softer	I or softer		J or softer	
Wheel Speed SFPM, Max	Internal cylindrical - 6000 Other - 4000	Low-under 3500		Low-under 3500	
Work Speed SFPM, Max	150	80		80	
Cross Feed - Surface, Inch per Pass, Max Cylindrical, External and Internal	0.100 1/4 wheel width per part revolution, max.	0.100 1/4 wheel width per part revolution, max.		0.100 1/4 wheel width per part revolution, max.	
Infeed (Downfeed) Inch per Pass, Max.		Surface and External Cylindrical	Internal	Surface and External Cylindrical	Internal
Rough	0.0002	0.0007 to within 0.005 inch of finish	0.0005 to 0.005 inch of finish	0.0008	0.0004
Finish	0.0002	0.0003	0.0002	0.0008	0.0004
Grinding Fluid	Oil base types shall be used.				

CAUTION

Centerless grinding will produce multi-lobe conditions on parts. Caution must be exercised to determine actual lobing condition as this will effect actual diameter of the part.

3.3.2 Centerless grinding. All centerless grinding shall be accomplished in accordance with 3.3.2.1 and 3.3.2.2 herein.

3.3.2.1 Limitations. Centerless grinding limitations shall be as specified in Table II.

TABLE II. CENTERLESS GRINDING LIMITATIONS FOR HARDENED STEEL AND CHROME PLATE ON HARDENED STEEL

Parameter	Chrome Plate	Hardened Steel
Wheel Grade	I or softer	I or softer
Wheel Speed SFPM, Max.	4000	Low-under 3500
Diametric metal removal rate per pass, inch per inch of wheel width, max.		
Rough (to within 0.002 inch of finish)	0.0003	0.0005
Finish	0.0008	0.0008
Grinding Fluid	Oil base types shall be used.	

3.3.2.2 Technique data cards. Centerless grinding shall meet the requirements of a technique data card established for each part.

3.3.2.2.1 The technique specified on the data card shall have been demonstrated to produce ground surfaces in conformance to the requirements of the engineering drawing.

3.3.2.2.2 A record of all changes in technique data cards showing effectivity (date or serial number) shall be maintained. The technique data card shall include the following information and other pertinent data as required:

a. Part number.

b. Outline of surfaces to be ground.

c. Grinding machines authorized for use.

d. Required tooling.

e. Wheel speed.

f. Part through feed speed.

g. Regulating wheel angle.

h. Vertical position and rake angle of work-rest blade.

i. Metal removal rate per pass.

j. Wheel dressing practice, including number of passes between redressing for both rough and finish grinding.

k. Coolant - type, supply rate, and nozzle location.

NOTE

Tolerances for operating variables shall be noted.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to Hughes Helicopters. Hughes Helicopters reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that suppliers and services conform to prescribed requirements.

4.2 Test methods. Tests and inspections shall be performed to assure conformance to the requirements of Section 3.

4.3 Acceptance inspection.

4.3.1 Etching of hardened steel. The following inspections shall be performed after grinding of unplated steel.

a. Surfaces of parts ground after hardening shall be etched in accordance with HP 30-4 and inspected for surface effects. Etching shall be performed prior to any operation altering the ground surface, including but not limited to polishing, honing, lapping, shot peening and heating.

b. Parts shall be embrittlement relieved in accordance with HP 1-9 prior to honing, lapping, shot peening, and plating when etching is performed in accordance with HP 30-4.

c. Parts and stock etched in accordance with HP 30-4 shall be examined visually in good light by qualified personnel. Surfaces of parts and stock shall be uniform in color and free of the following indications:

(1) Dark areas - Indicative of overtempering.

(2) Light area within dark area - Indicative of the presence of a rehardened zone from heat generated during grinding surrounded by a transition zone of annealed and overtempered metal.

(3) Cracks - Indicative of presence of high stresses induced during grinding.

Parts and stock showing any of the above indications shall be rejected.

4.3.2 Magnetic particle inspection. Parts shall be magnetic particle inspected in accordance with HP 6-5 after grinding.

4.4 Records. Records shall be retained for 3 years after completion of the contract.

4.5 Reports. Unless otherwise specified, the vendor of the product shall furnish with each shipment three copies of a report of the results of all tests performed for determining conformance to the technical requirements of this specification. This report shall include the purchase order number material specification number with revision date, and size and quantity from each heat. When forgings are supplied, the lot number and part number, shall be included in the report.

5. PREPARATION FOR DELIVERY

5.1 All parts shall be processed in accordance with HP 4-1 prior to delivery or storage.

6. NOTES

7. APPROVED VENDORS

7.1 Only vendors listed on Hughes Helicopters Approved Vendors List (AVL) 18-12 shall perform this process.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
CONVENTIONAL MACHINING OF ESR 4340 STEEL -
K.K. Niji

Technical Report AMMRC TR 80-F-14, July 1980,
illus-table, D/A Project 1787240, 104 pp -
AMCMS Code 1497017240XT8

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Tool life
Cutting rates
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Turning

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